2nd Advanced Training Course on
"Illicit trafficking and Radiological Consequences" with Nucleonica
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Gamma Spectrum Generator

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nucleonica

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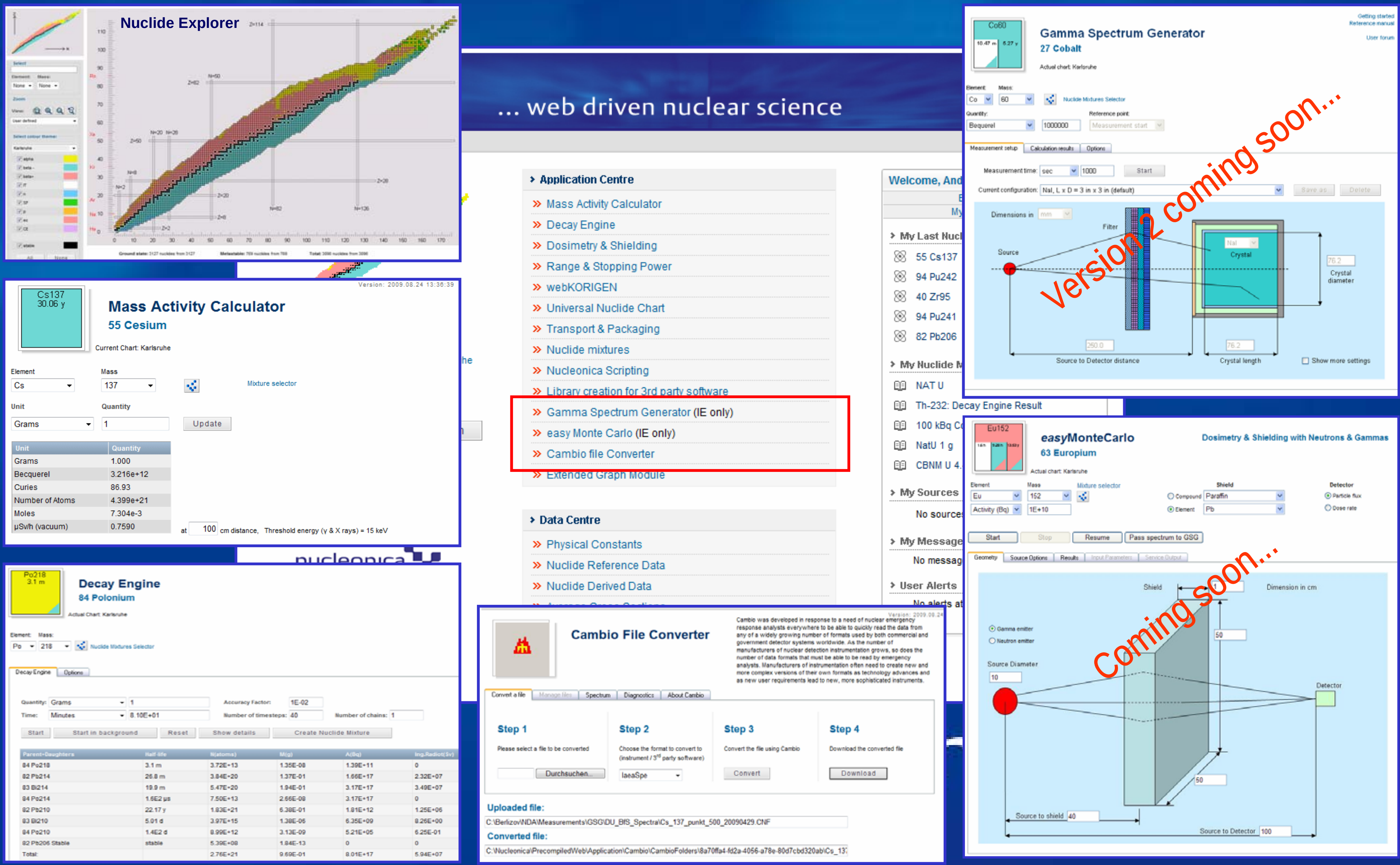
Nucleonica's unique feature: Web-based Nuclear Science Applications



Outline

- **GSG Version 1 (*point-like slightly shielded sources*)**
  - Introduction to GSG features
  - Spectrum modeling examples
  - Experimental validation

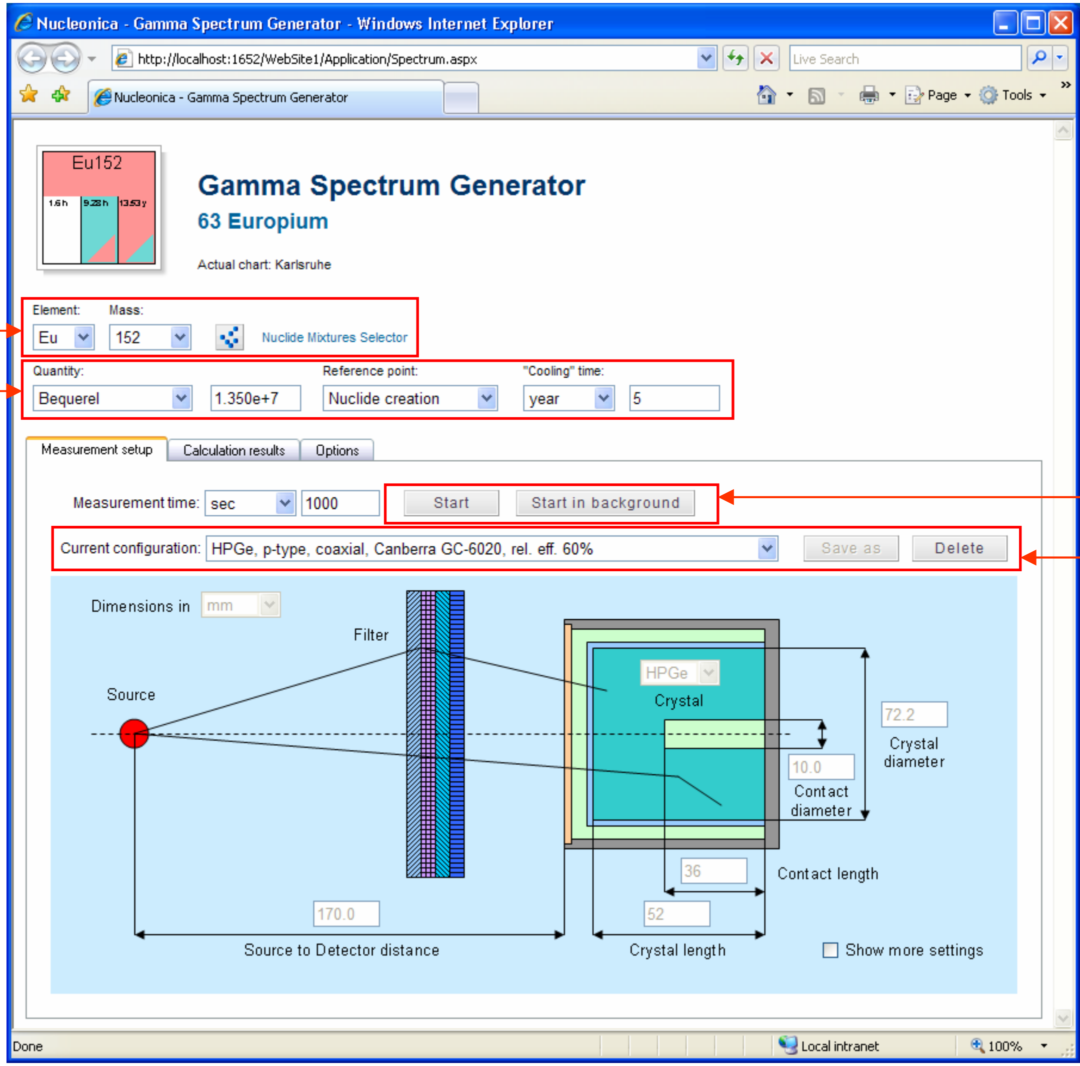
- **GSG Version 2 (*extended & heavily shielded sources*)**
  - Highlights of new features
  - Introduction to EMC & coupled EMC-GSG simulations
  - Experimental validation

- **Exercises**

Features implemented: Measurement setup

An arbitrary individual nuclide or a pre-defined mixture of nuclides can be selected as a radiation source

The quantity (activity, mass or number of atoms) of a nuclide or a mixture can be specified either at the moment of its production or at the spectrum measurement starting point of time. In the former case controls for specifying duration of a source cooling time interval become available.



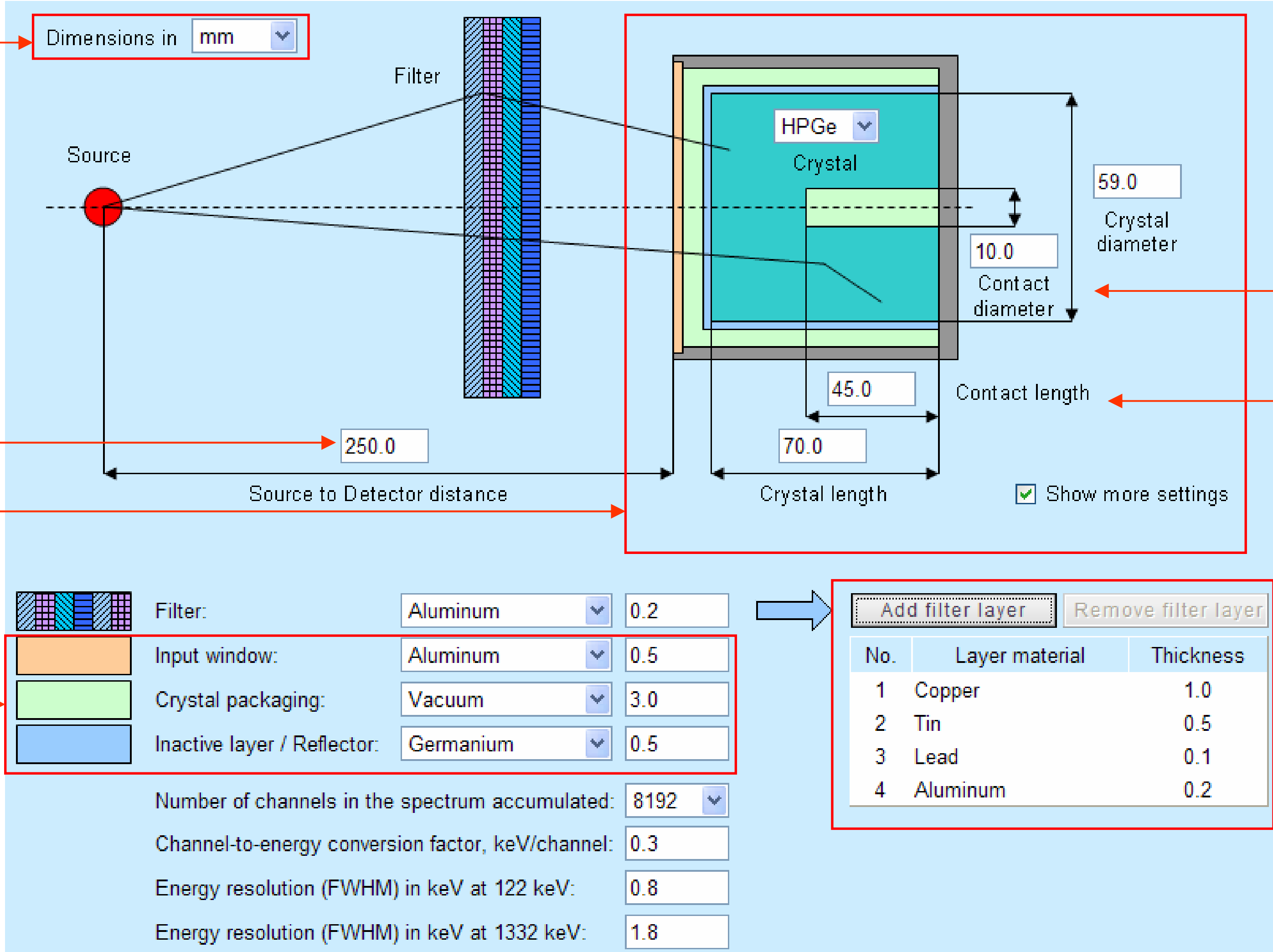
Calculations can be started on-line or in a background mode

A suitable γ-spectrometer can be chosen from 6 pre-defined configurations, which include 2 coaxial HPGe (50% and 150%) detectors, low-energy (LEGe) and broad-energy (BEGe) HPGe detectors, and 2 NaI detectors (∅3″×3″ and ∅2″×1″). In addition, user's specific configurations can be managed.

Features implemented: Measurement setup

Dimensions can be entered in “mm”, “cm” or “inch” units

The configurable parameters include the source-to-detector distance, as well as dimensions and materials of the detector construction elements.



No.	Layer material	Thickness
1	Copper	1.0
2	Tin	0.5
3	Lead	0.1
4	Aluminum	0.2

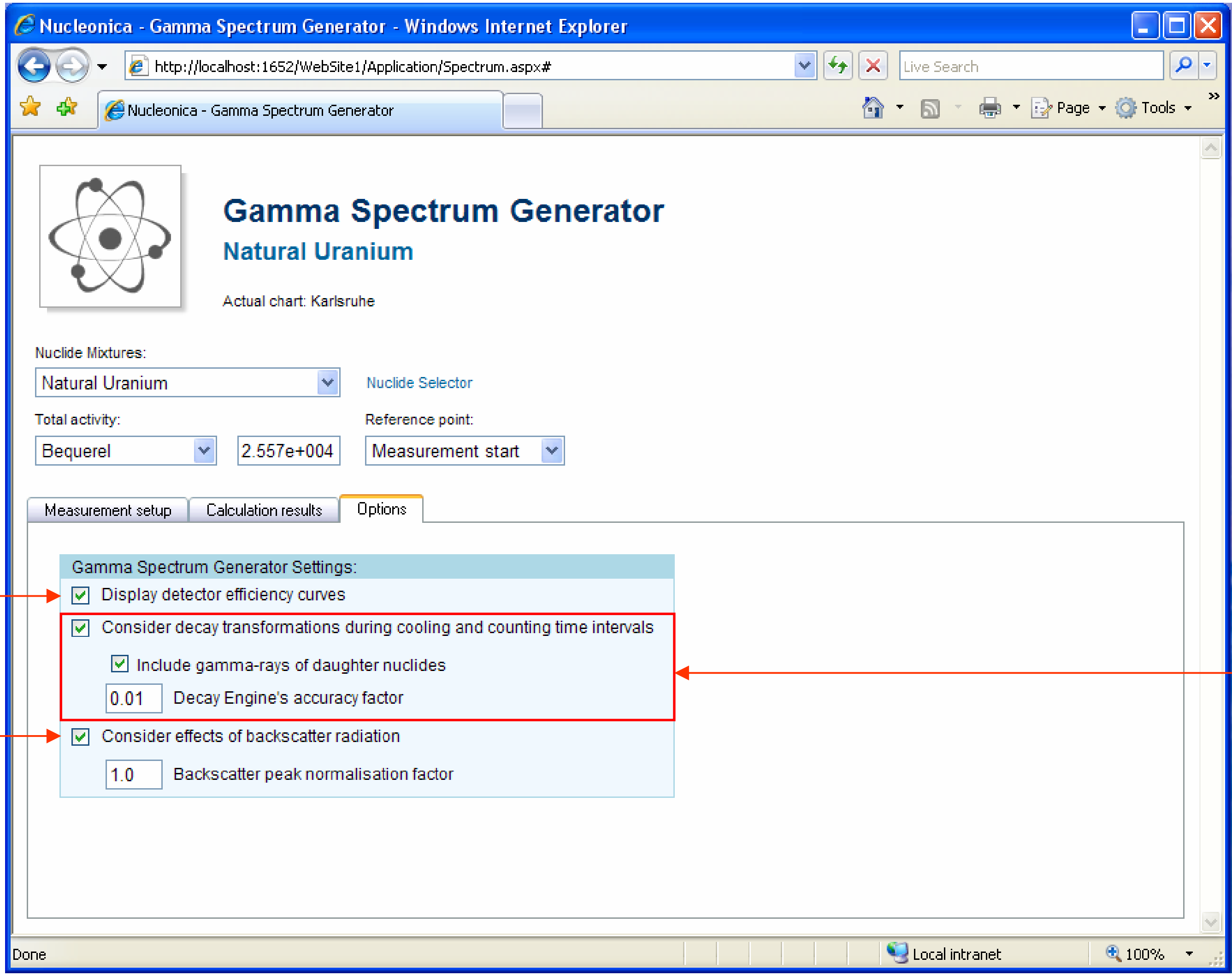
The dimensions of a cylindrical contact at the rear side of the crystal (a construction feature of conventional coaxial HPGe detectors) can be specified

Up to 6 additional absorbing filters made of Al, Cu, Fe, Pb, Sn, or polyethylene can be placed between source and detector

Features implemented: Options

Efficiency Graph can be activated in the Calculation Results output

The backscatter peak simulation can be switched on/off, and its contribution to the spectrum can be adjusted



Decay calculations can be enabled that will allow contributions from decay products, being accumulated during source cooling and spectrum measurement time intervals

Features implemented: Calculation results

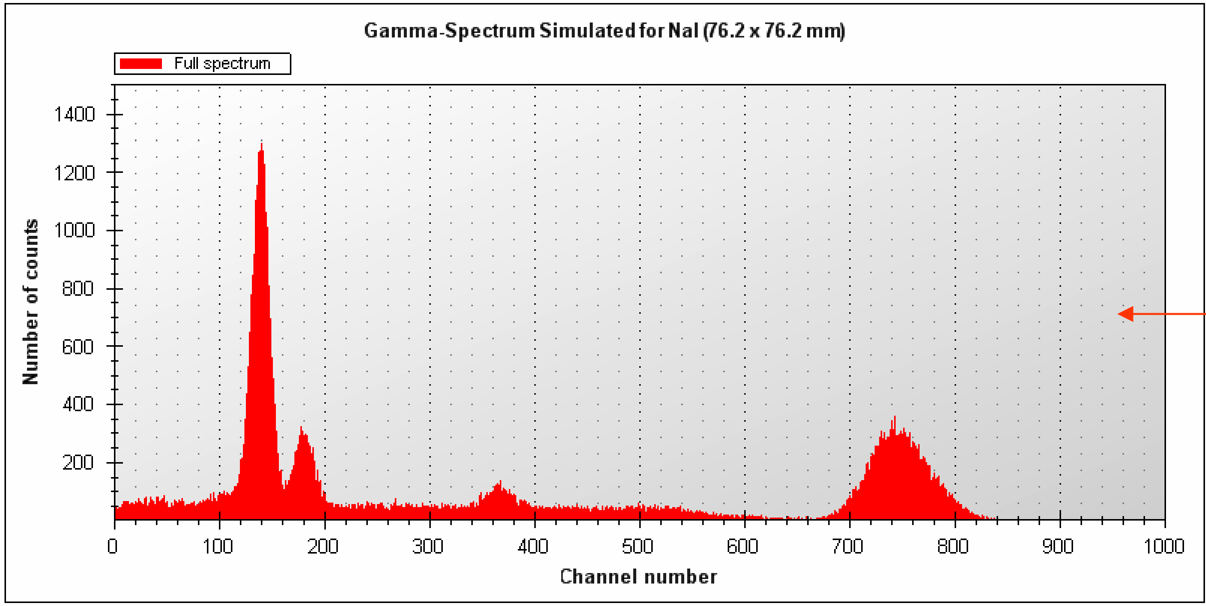
Statistical number of counts
- Count rate at start
- Count rate at end
- Theoretical number of counts
- Statistical number of counts

Measurement setup | Calculation results | Options

Data displayed: Statistical number of counts

View/Save results in Text or Excel format

Complete set of spectral information can be downloaded as a text or Excel spreadsheet file



Right click within the graph area enables a context menu, from which one can print or download the spectrum graph

Update spectrum graph

Display: ☐ Energy scale ☐ Spectrum continuum ☐ Contribution of scattered photons ☐ More graph options

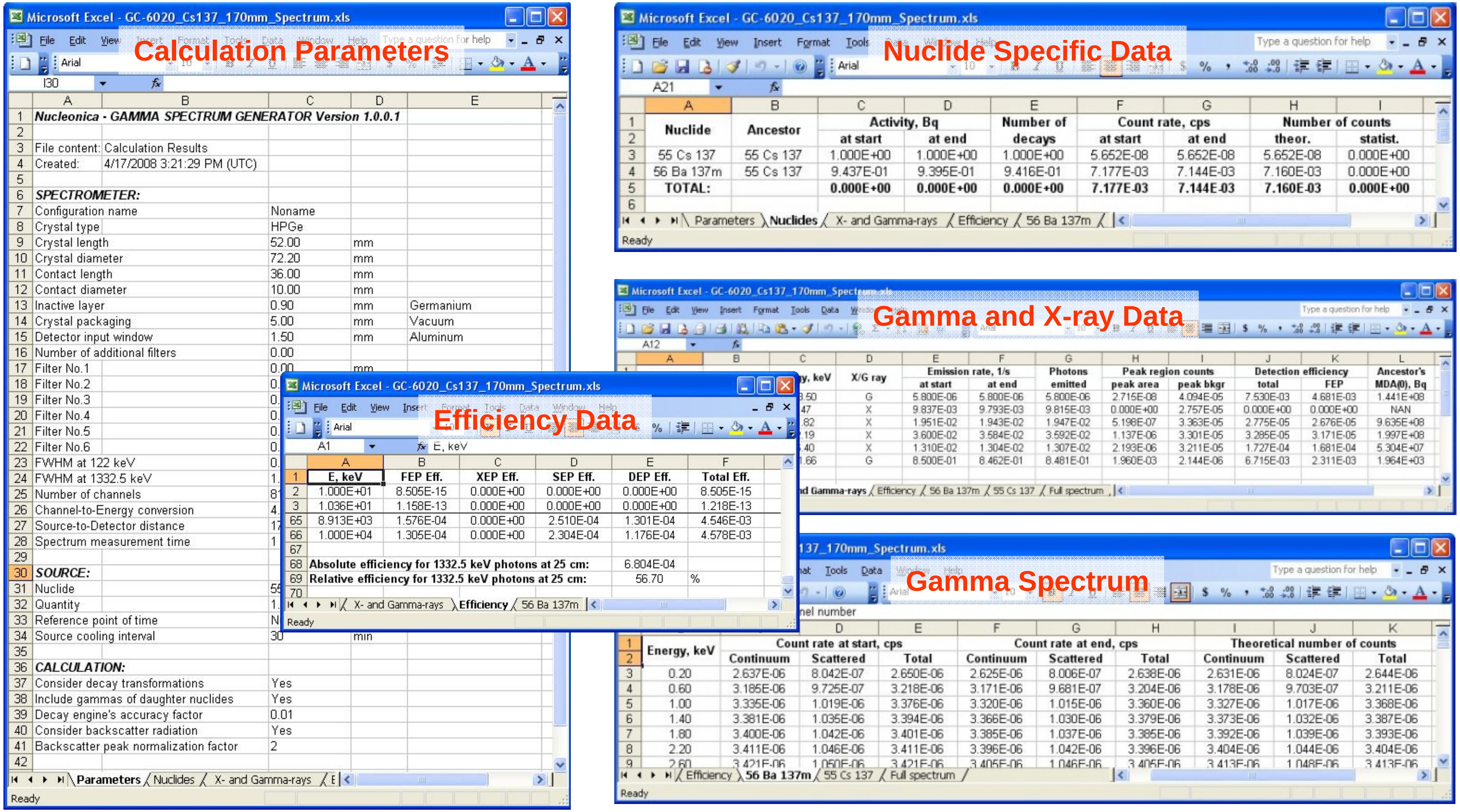
Switch between channel number and energy scale; show peak, continuum and backscatter peak contributions to the full spectrum

Additional options allow to customize appearance of the graph to meet one's needs and requirements

No.	Nuclide	Count rate at start, cps	Count rate at end, cps	Spectrum counts	Display
1	42 Mo 99	6.23E+01	6.22E+01	6.26E+04	☐
2	43 Tc 99	6.70E-15	6.79E-15	0.00E+00	☐
3	43 Tc 99m	2.69E+01	2.68E+01	2.70E+04	☐
	Total	**8.92E+01**	**8.90E+01**	**8.97E+04**	

Display nuclide specific contributions to the full spectrum

Calculation results : Detailed Spectral Data in Excel Spreadsheet



Calculation results : Detection Efficiency

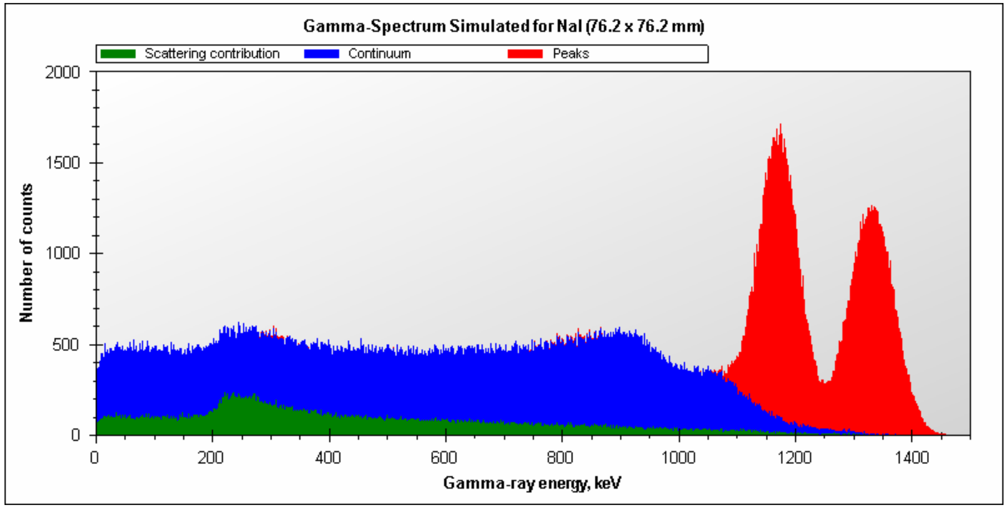
Right click within the graph area enables a context menu, from which one can print or download the efficiency graph

Select efficiency data to be displayed on the graph

Additional options allow to tailor the efficiency graph to one's needs and requirements

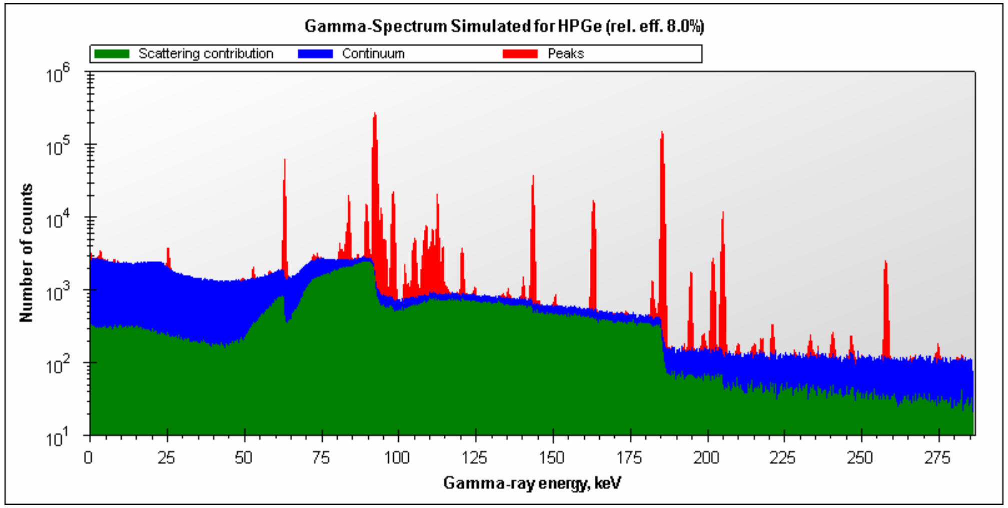
Examples:

100 kBq ^{60}Co



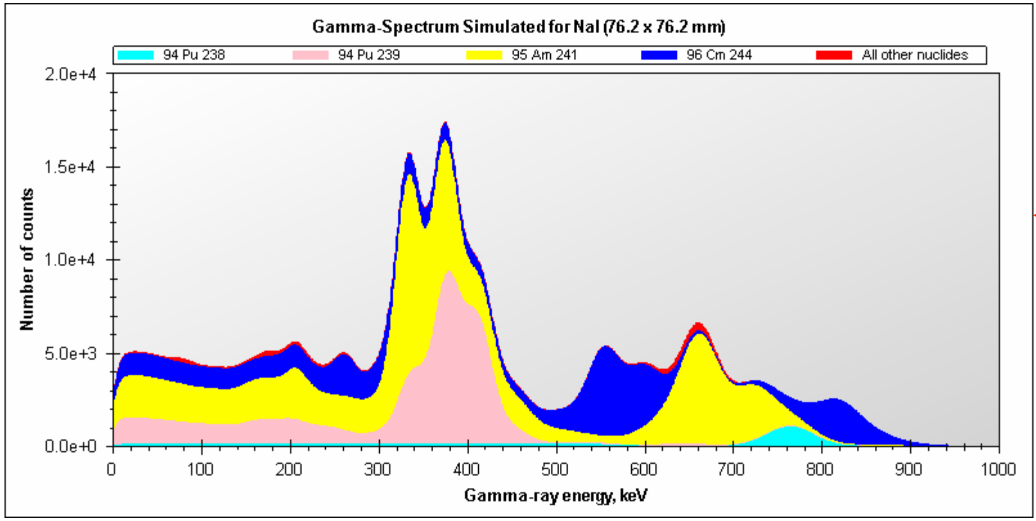
Detector - NaI (∅3″×3″)
Source-to-detector distance - 25 cm
Measurement time - 1000 s

1 g Nat U (2 years after separation)



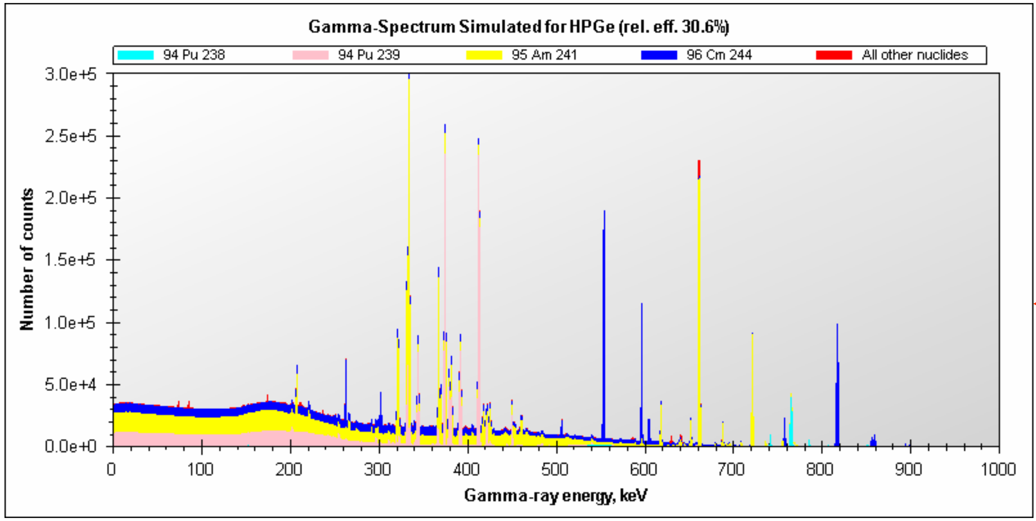
Detector – LEGe (20 mm × 2800 mm^2)
Source-to-detector distance – 25 mm
Filter – 0.5 mm Sn
Measurement time - 10^5 s

Examples:



Detector – NaI (∅3″×3″)
Source-to-detector distance – 25 cm
Filter – 5 mm Pb
Measurement time - 1000 s

Actinides extracted from 1 kg 6-year-aged PWR spent fuel. Activity - 5.25 TBq



Detector – BEGe (30% rel. eff.)
Source-to-detector distance – 25 cm
Filter – 5 mm Pb
Measurement time - 1000 s

Experimental validation with 60% HPGe coaxial detector (INR, Kiev)

Detector: coaxial HPGe (Canberra)

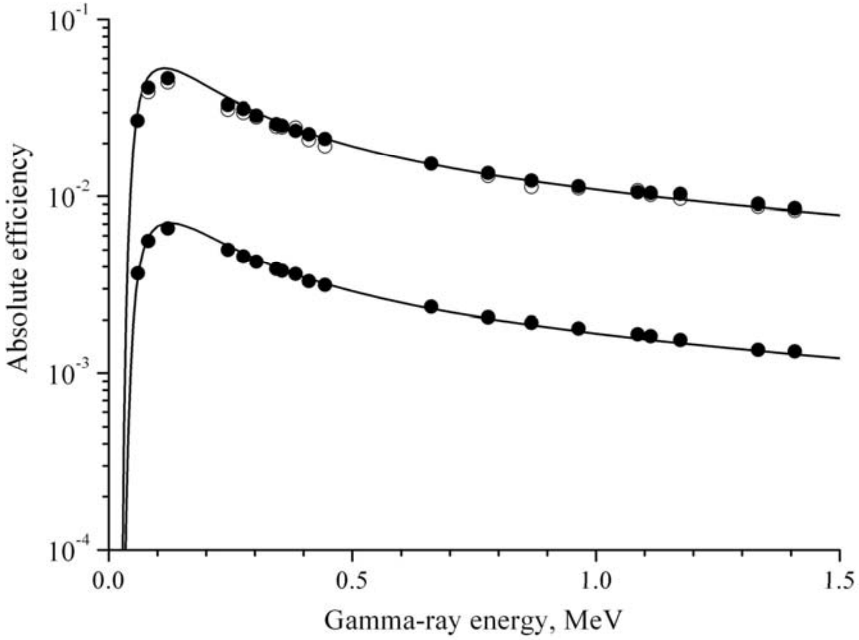
- Relative efficiency: 61.8%
- Crystal dimensions: ∅74 mm × 53 mm
- Rear contact: ∅10 mm × 36 mm
- Inactive Ge: 0.7 mm
- Crystal end cap: 1.5 mm Al
- End cap to crystal gap: 5 mm
- FWHM: 1.75 keV at 1.33 MeV

Sources: Thin Spectroscopic Reference Gamma-Sources (SOSGI)

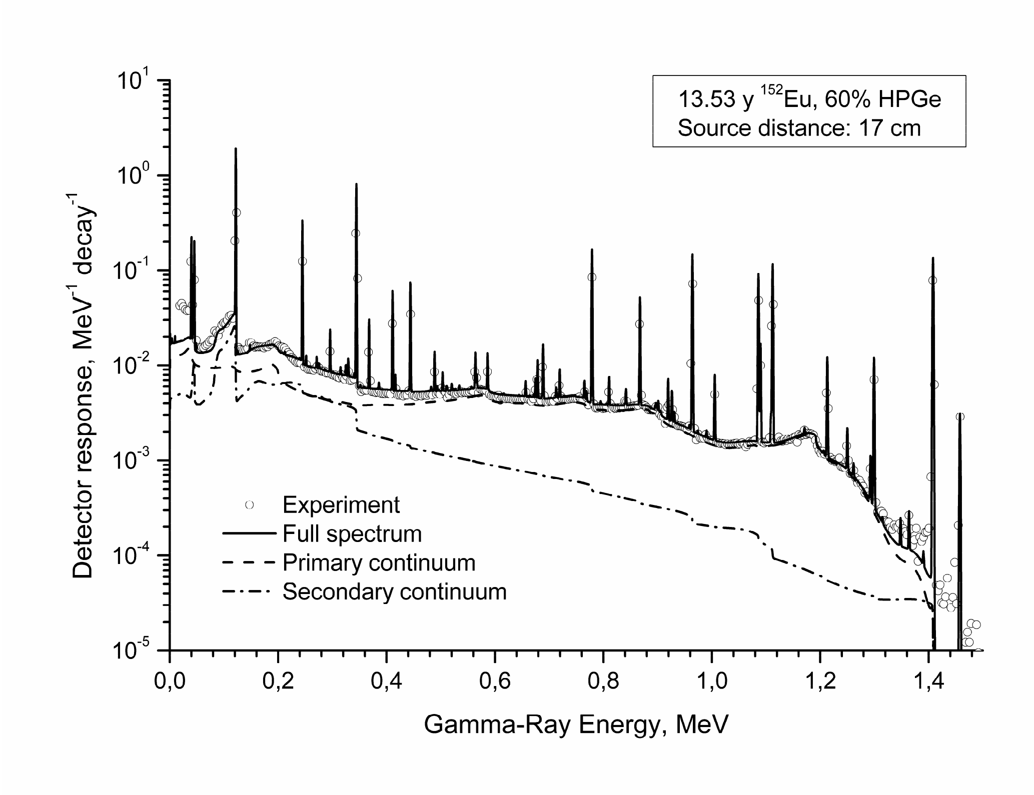
- ^{137}Cs, ^{60}Co, ^{152}Eu

Measurement conditions: Center of experimental room

Results of the experimental validation with 60% HPGe coaxial detector



Full Energy Peak efficiency as a function of the photon energy: circles – experimental values, curve – calculated. Two sets of data refer to the source location at 5 cm and 17 cm distances from the detector end cap.



Calculated (curve) and experimental (circles) detector responses for ^{152}Eu source at 17 cm distance from the detector end cap.

GSG Version 1: Experimental Validation (NaI)

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ORIGINAL ISSUED: AUGUST 1964
REV. ELECTRONIC UPDATE:: FEBRUARY 1997

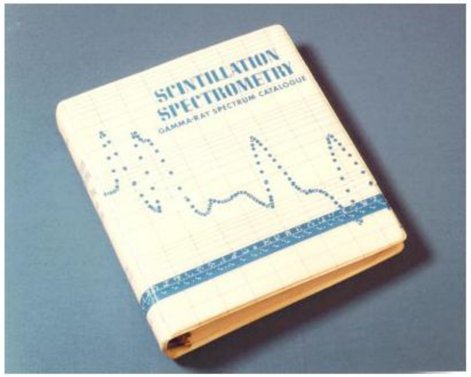
SCINTILLATION SPECTROMETRY

GAMMA-RAY SPECTRUM CATALOGUE

NEW VERSION OF 2ND EDITION
COMPILATION OF GAMMA-RAY SPECTRA
AND RELATED NUDCLEAR DECAY DATA
VOLUME 1 OF 2

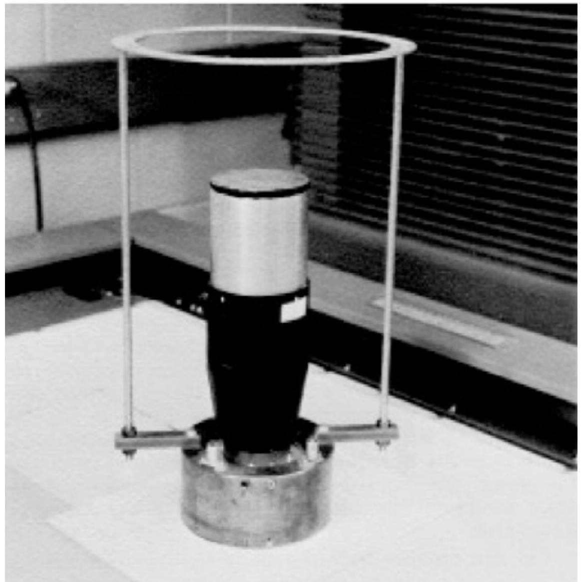
BY

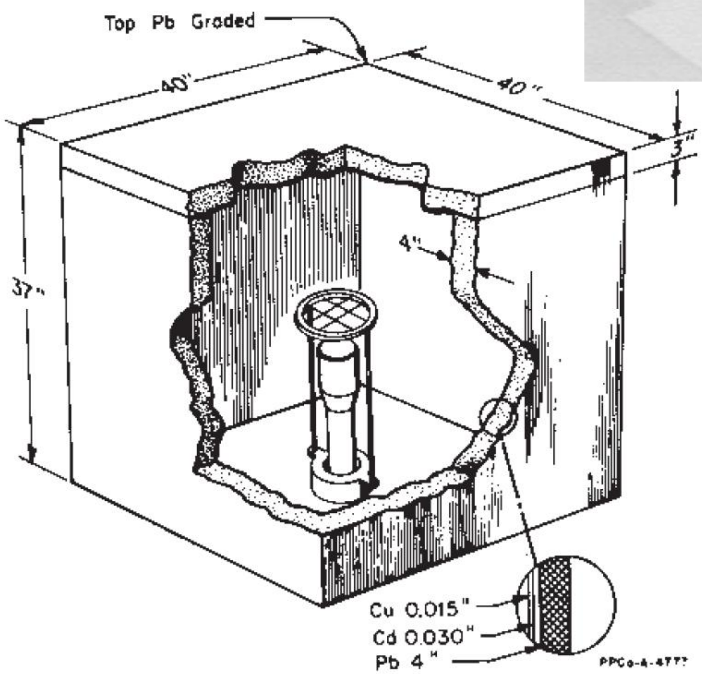
R. L. HEATH



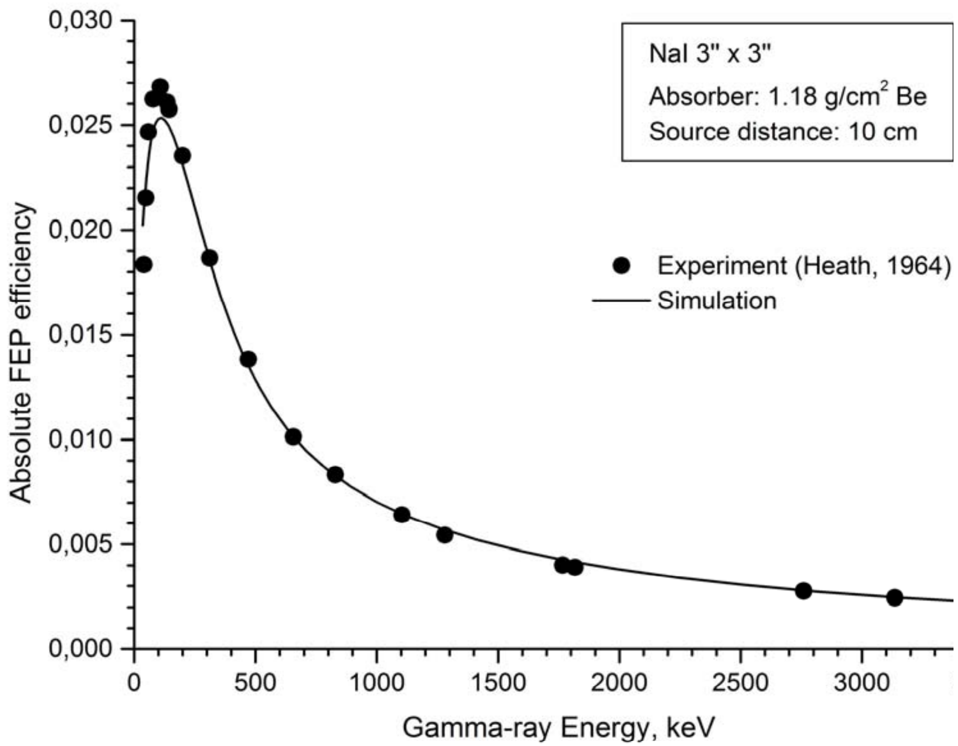
-RAY SPECTROMETRY CENTER
Idaho National Engineering & Environmental Laboratory

Detector:
3″ × 3″ NaI scintillation detector

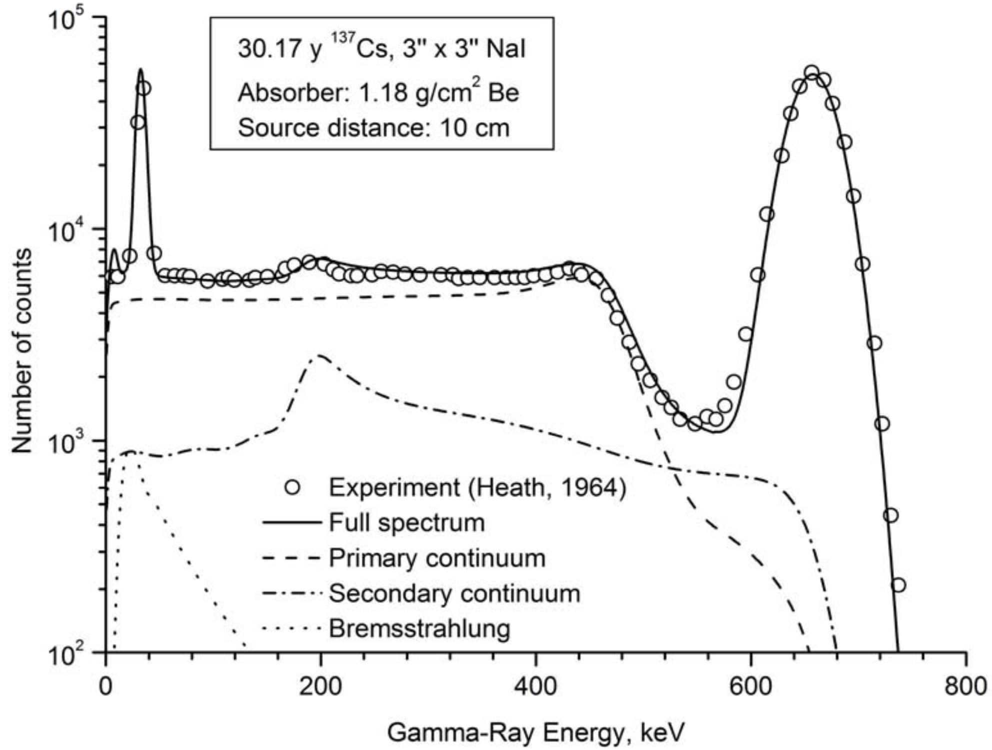




Results of the experimental validation with 3″ × 3″ NaI scintillation detector



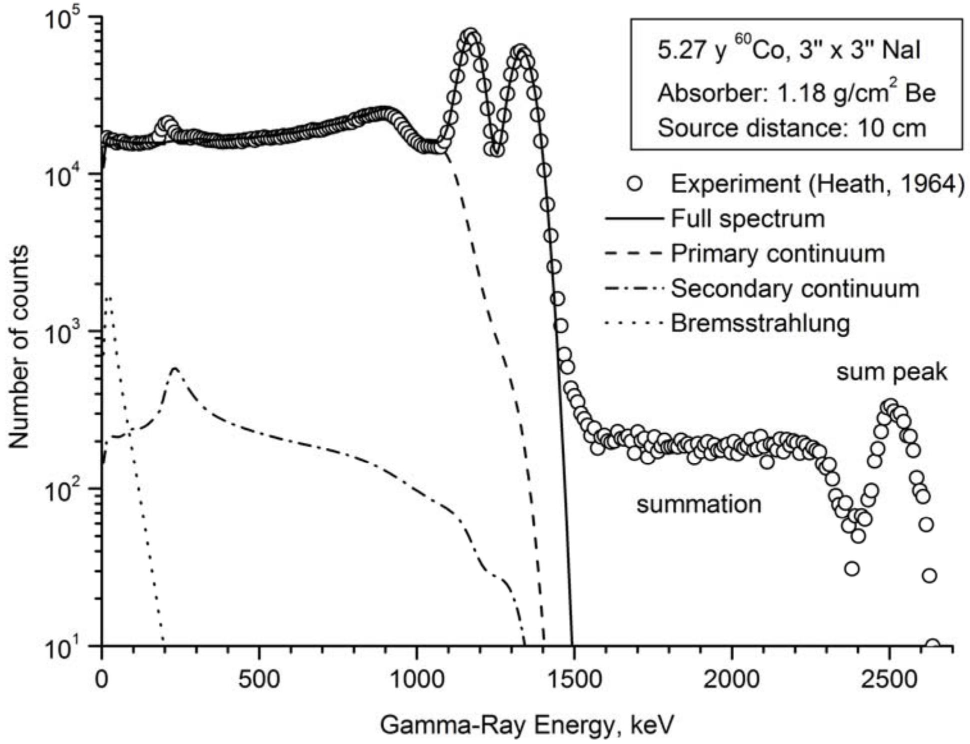
The simulated vs. experimental *FEP* efficiencies for a NaI 3″ × 3″ detector.



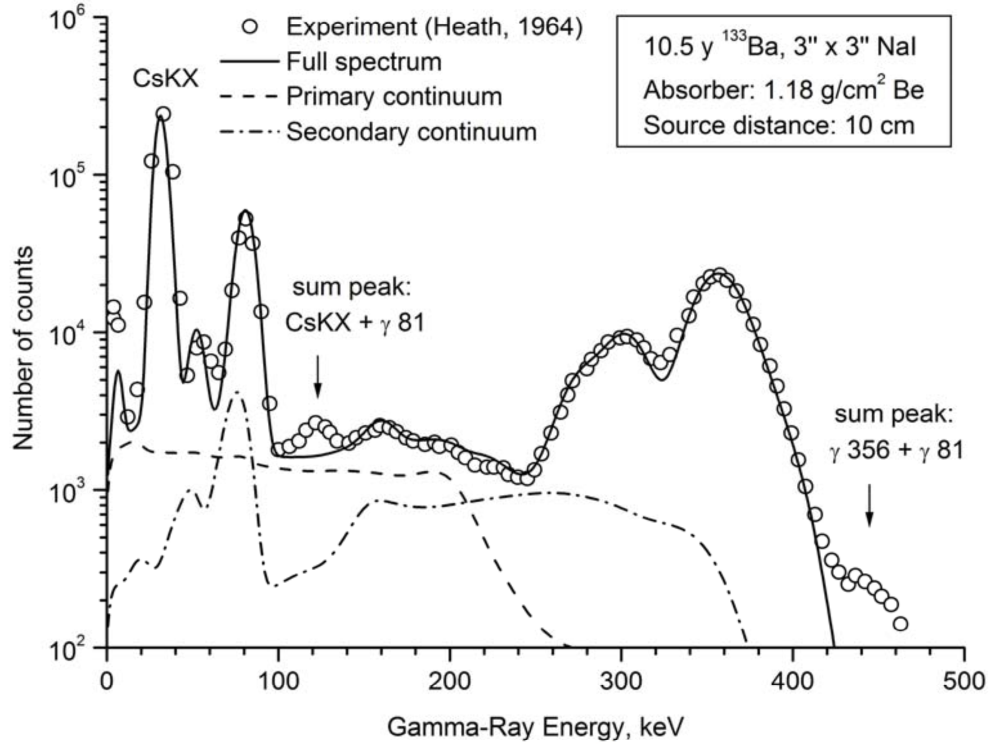
The experimental and simulated spectra for ^{137}Cs and a NaI 3″ × 3″ detector .

GSG Version 1: Experimental Validation (NaI)

Results of the experimental validation with 3″ × 3″ NaI scintillation detector

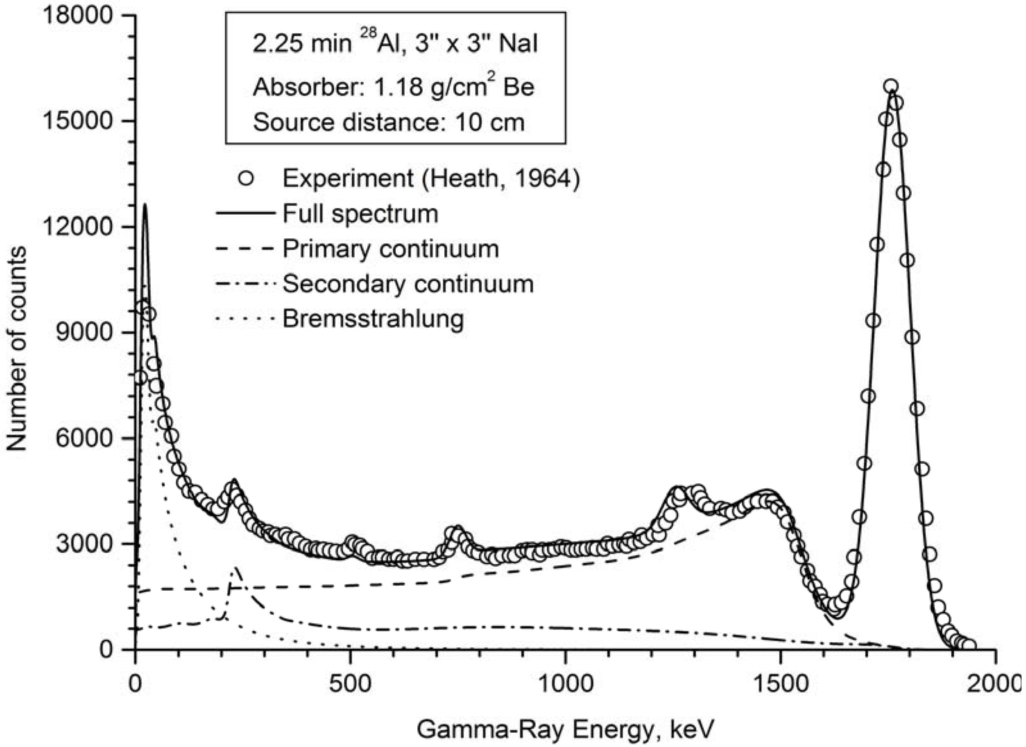


The experimental and simulated spectra for ^{60}Co and a NaI 3′′ × 3′′ detector.

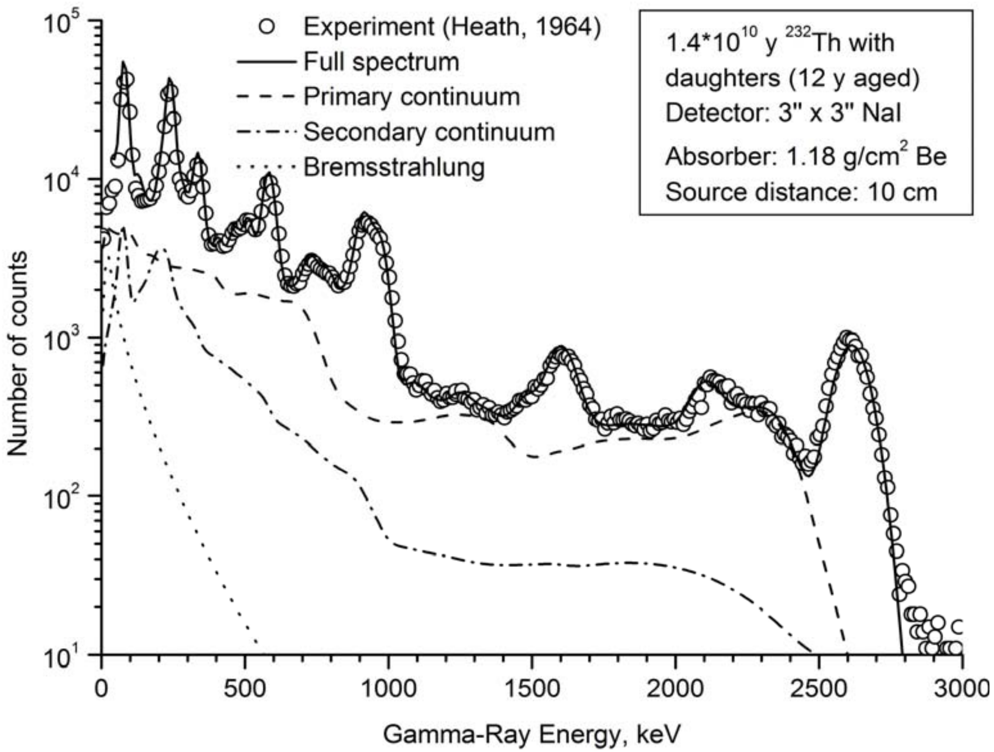


The experimental and simulated spectra for ^{133}Ba and a NaI 3′′ × 3′′ detector.

Results of the experimental validation with 3″ × 3″ NaI scintillation detector

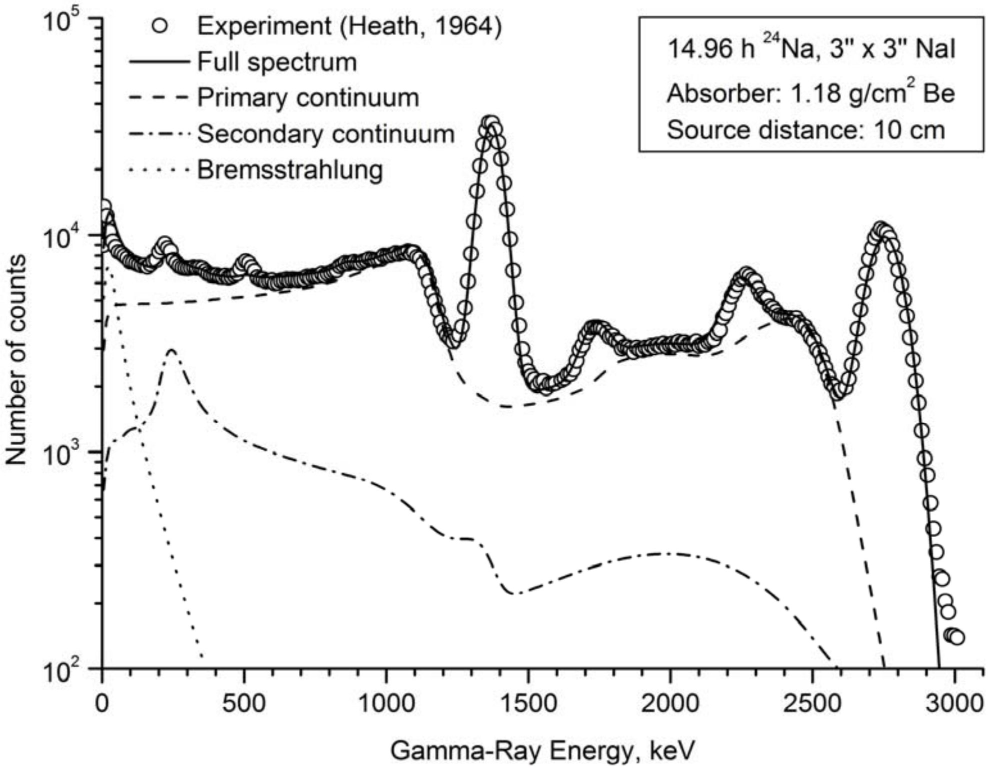


The experimental and simulated spectra for ^{28}Al and a NaI 3′′ × 3′′ detector .

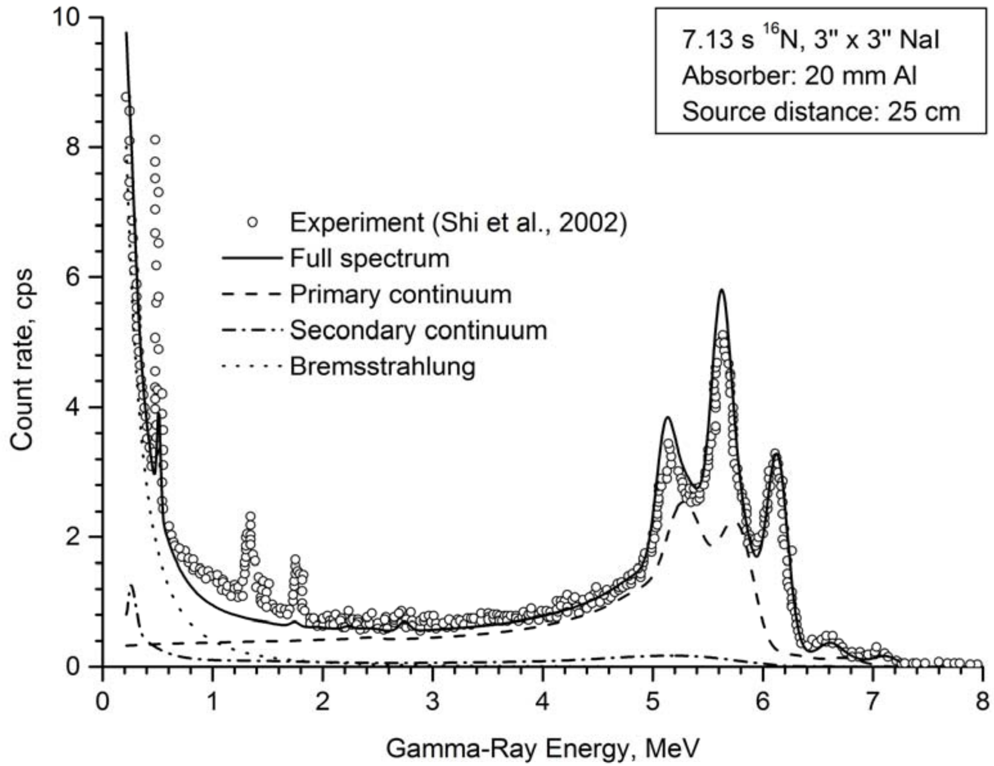


The experimental and simulated spectra for a 12 year old ^{232}Th source and a NaI 3′′ × 3′′ detector.

Results of the experimental validation with 3″ × 3″ NaI scintillation detector



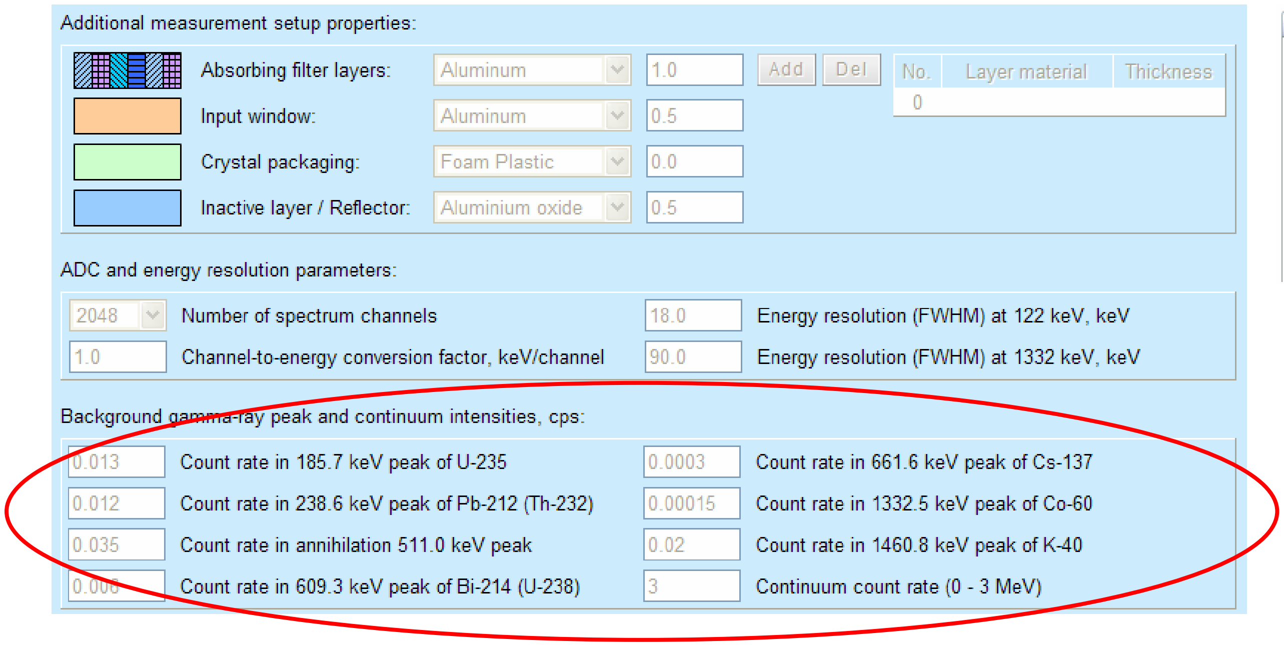
The experimental and simulated spectra for ^{24}Na and a NaI 3′′ × 3′′ detector.

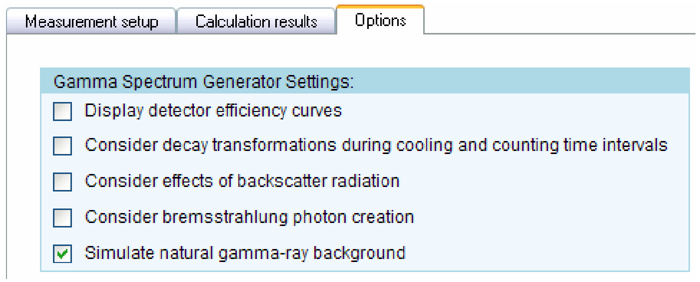


The experimental and simulated spectra for ^{16}N and a NaI 3′′ × 3′′ detector.

GSG Version 2: Highlights of new features

New feature #1: Modeling background gamma spectrum from naturally occurring radionuclides, which makes the spectrum shape and MDA evaluations to be more realistic

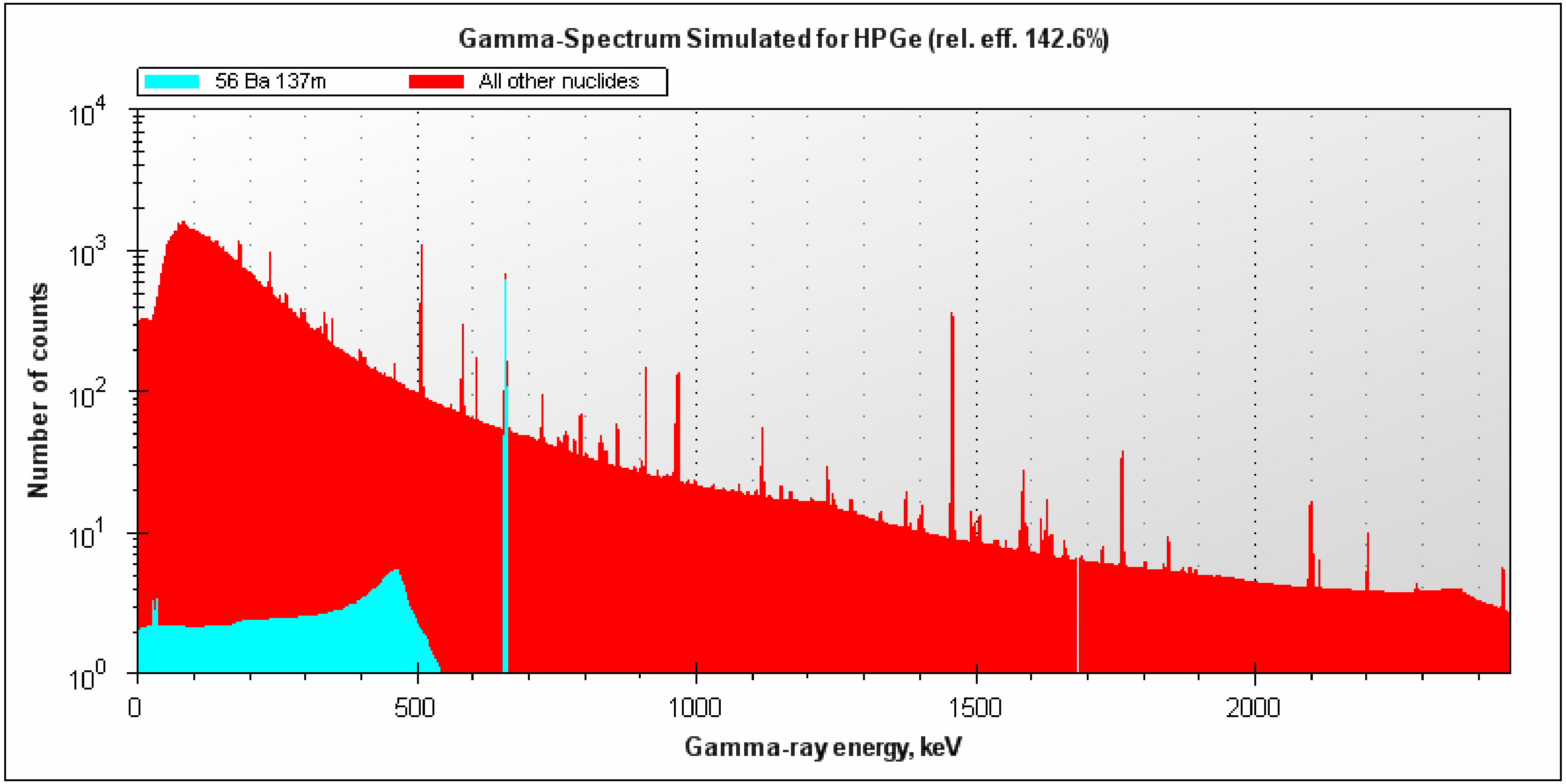




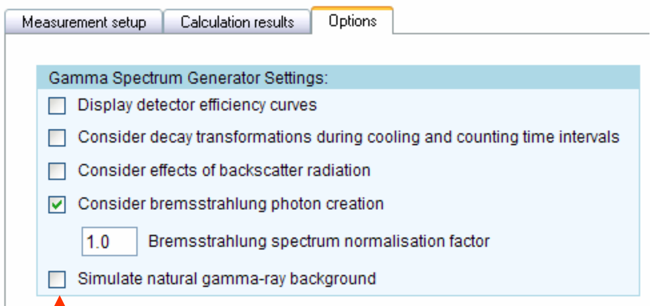
A respective option has to be selected on „Options“ tab to enable the background simulation

Example: Natural background simulation

- a 10 Bq ^{137}Cs source at 10 mm distance from 150% HPGe with natural background photons included

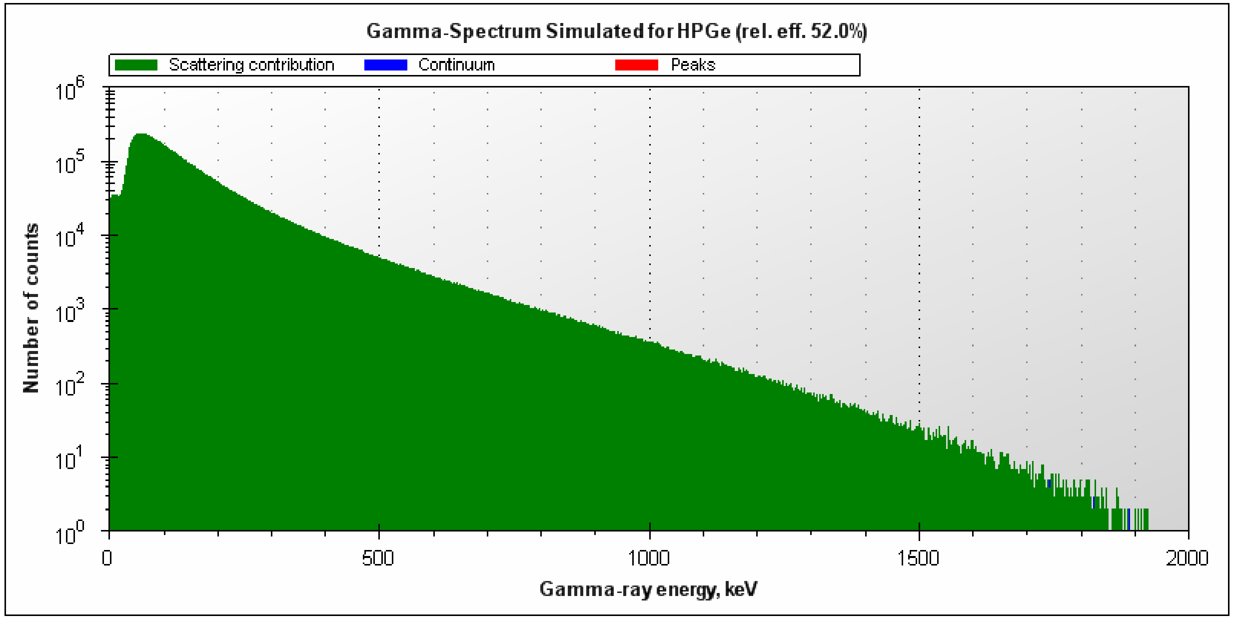


New feature #2: Bremsstrahlung simulation

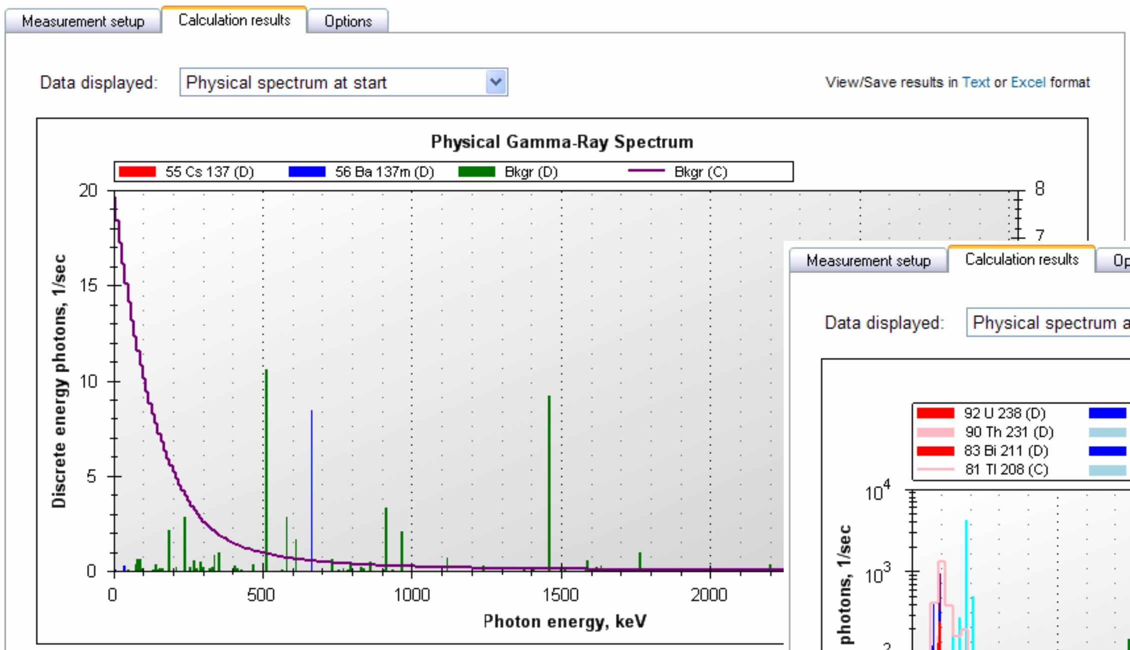


A respective option can be selected on „Options“ tab to enable the bremsstrahlung simulation.

A gamma-spectrum simulated for the 10 MBq ^{90}Sr-^{90}Y source and 50% HPGe

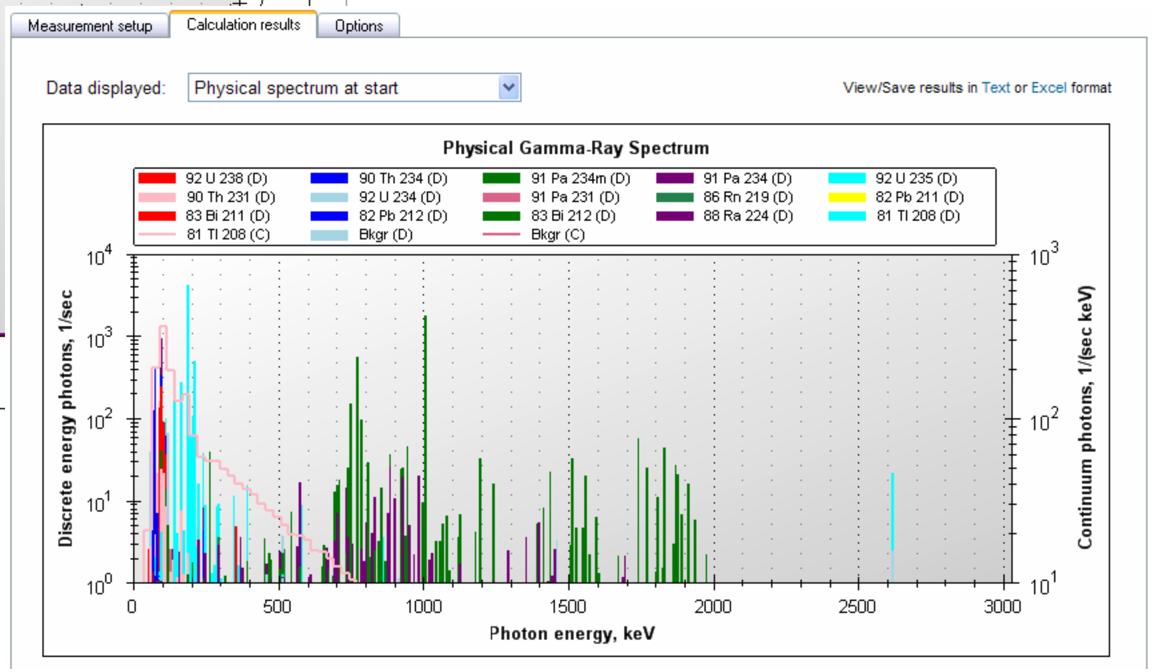


New feature #3: Physical photon spectrum visualization

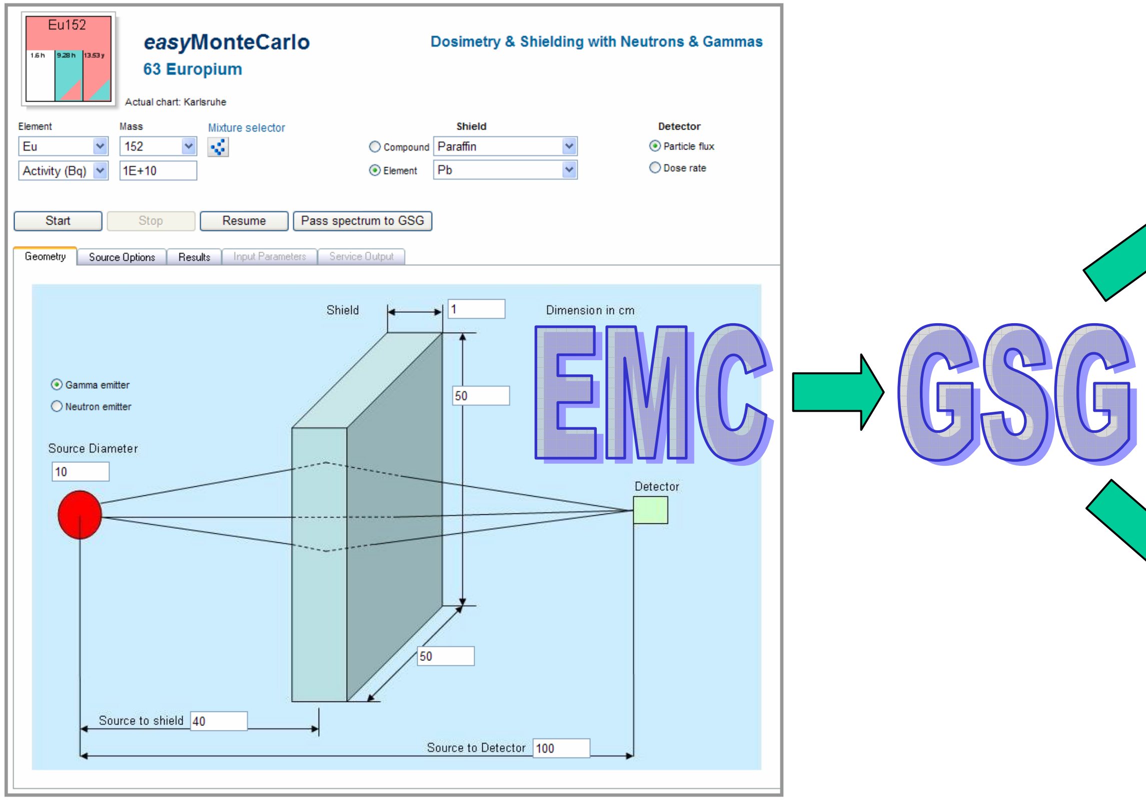


^{137}Cs source and natural background photons

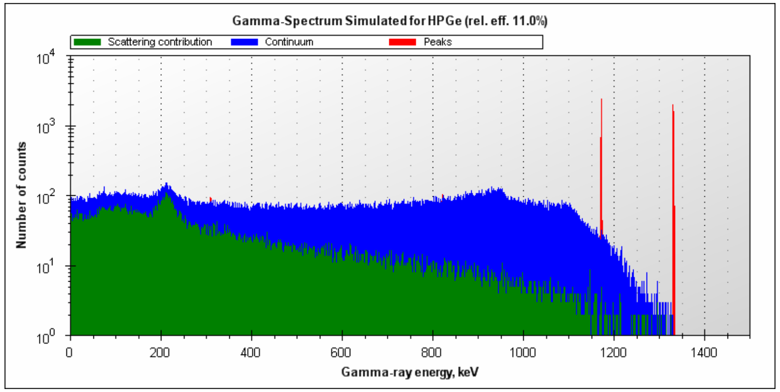
4.46% Uranium source and natural background photons



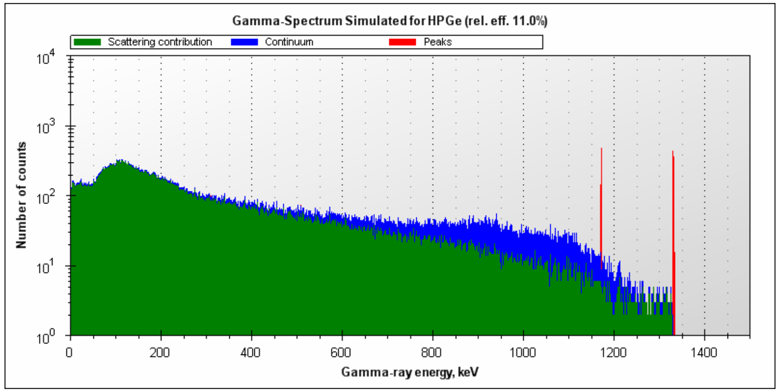
New feature #4: Including self-attenuation and scattering effects, which would allow more realistic simulation of gamma-spectra from voluminous and shielded sources



Unshielded ^{60}Co:

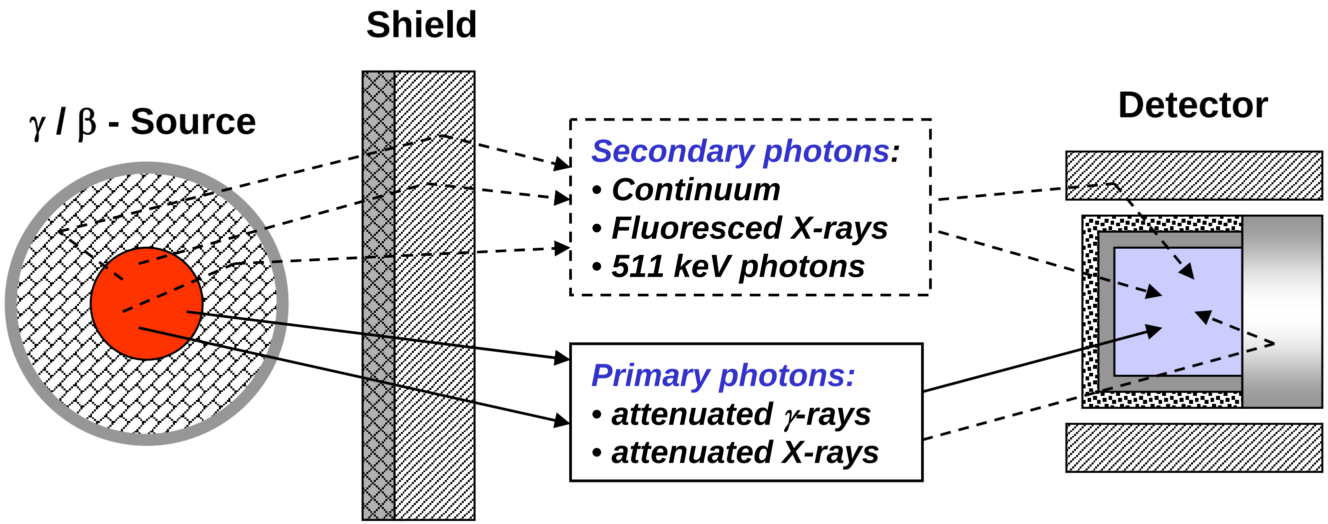


^{60}Co behind 12 cm Al shield:



Modelling γ-spectra from volume / shielded sources:

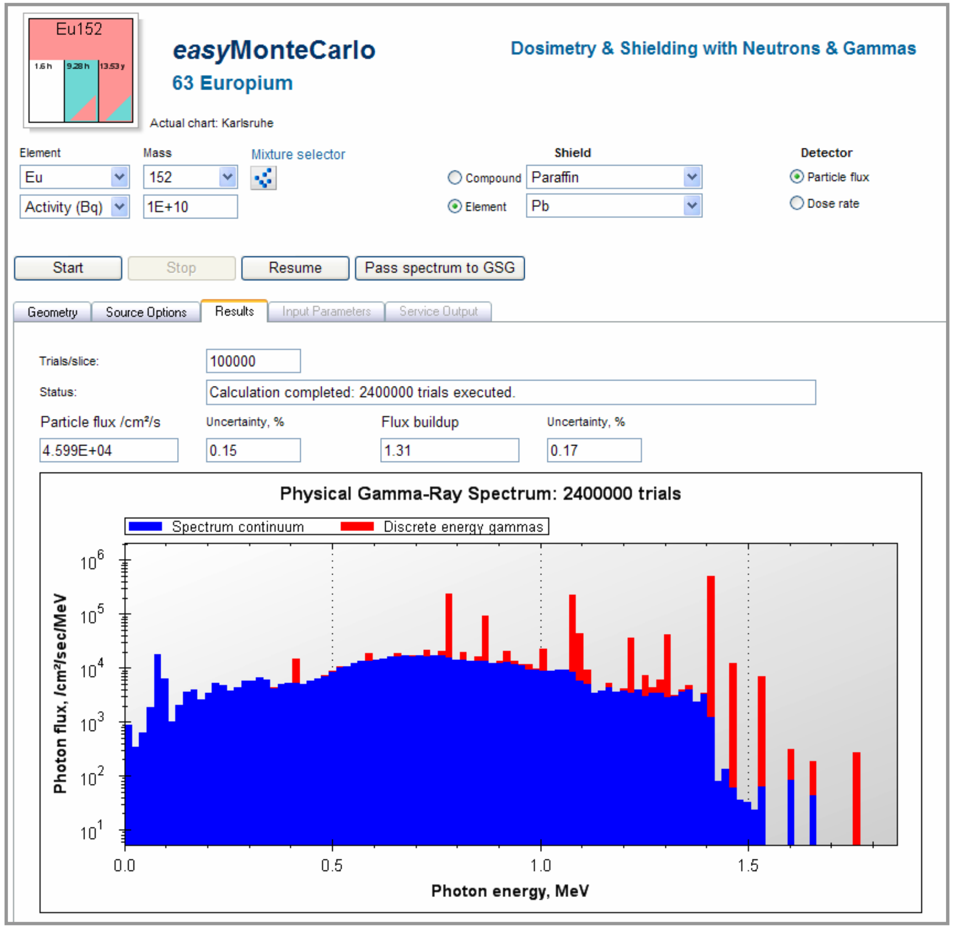
Effects:
- ***Self-attenuation***
- ***Attenuation***
- ***Scattering***
- ***Backscattering***
- ***X-ray fluorescence***
- ***Pair production***
- ***Bremsstrahlung***



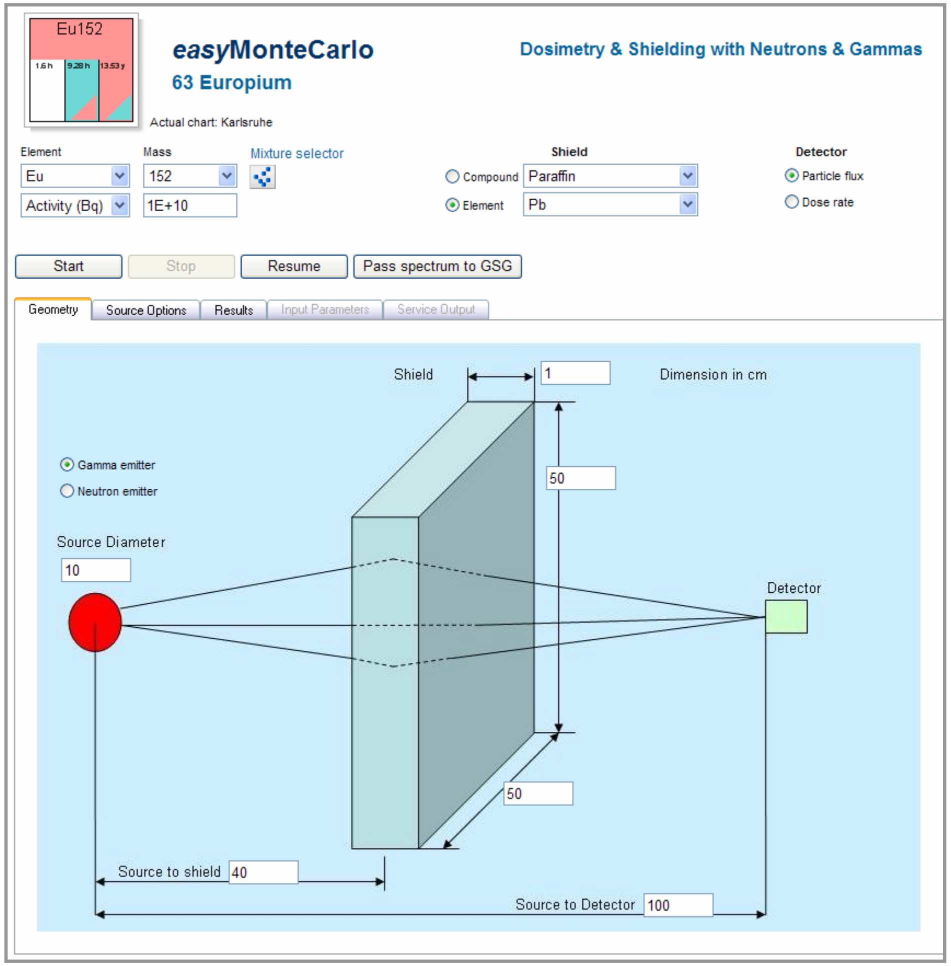
Challenges:
- **an accurate reproduction of the incident photon flux properties is important;**
- **an accurate knowledge of the detector response in a broad energy range is required;**
- **a huge computational effort is normally needed.**

What is the EasyMonteCarlo?

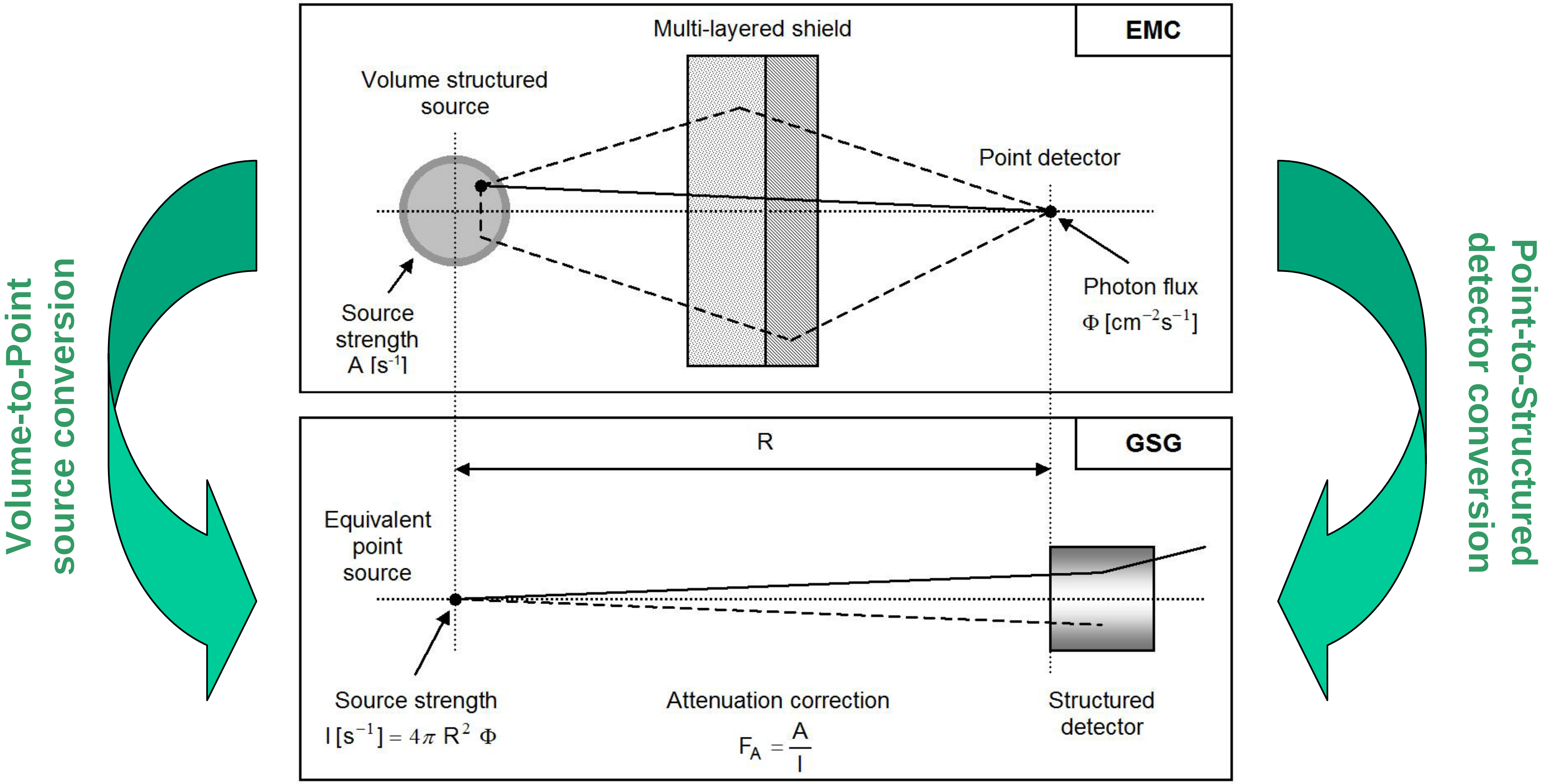
- **A dedicated Monte Carlo web-service, i.e. a computational engine reachable to other programs via the Internet**



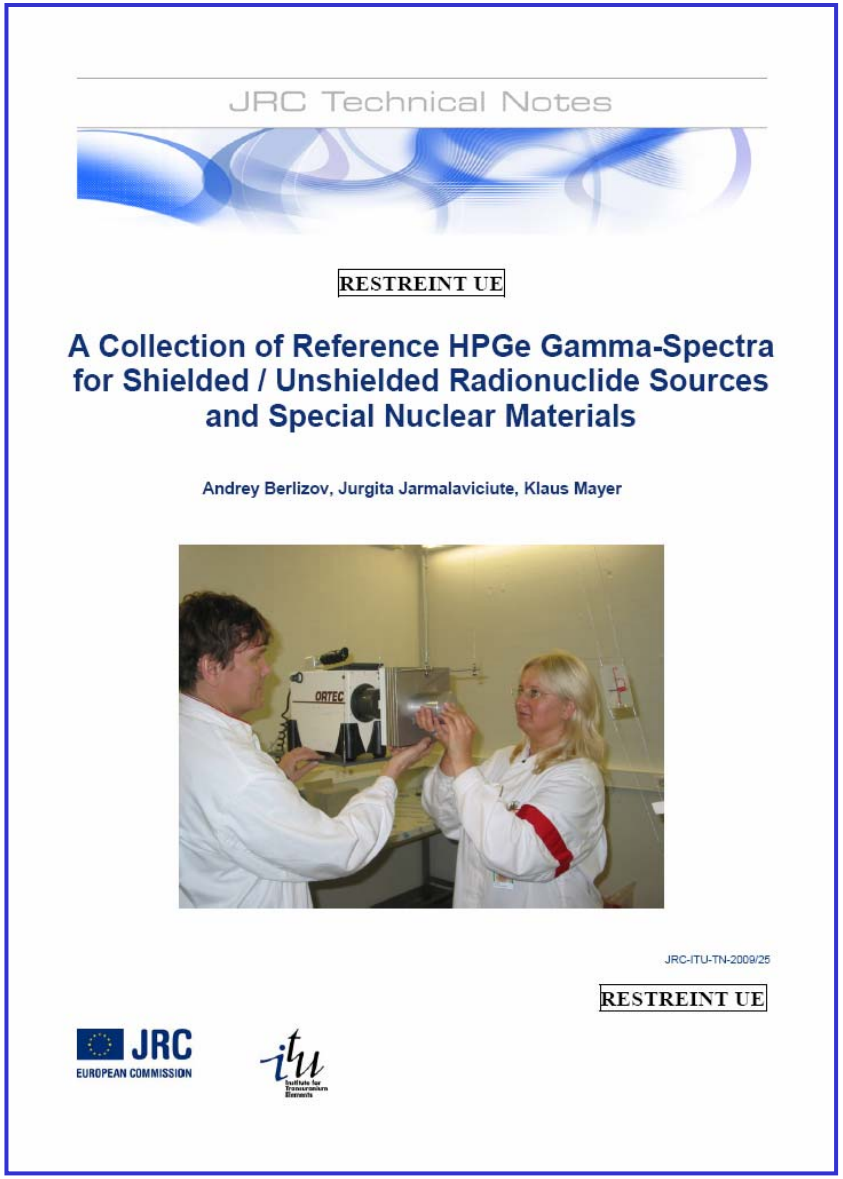
EMC Front End:



Coupled EMC / GSG calculations for voluminous & shielded sources:



GSG Version 2: Experimental Validation



JRC Technical Notes

RESTREINT UE

A Collection of Reference HPGe Gamma-Spectra for Shielded / Unshielded Radionuclide Sources and Special Nuclear Materials

Andrey Berlizov, Jurgita Jarmalaviciute, Klaus Mayer

JRC-ITU-TN-2009/25

RESTREINT UE

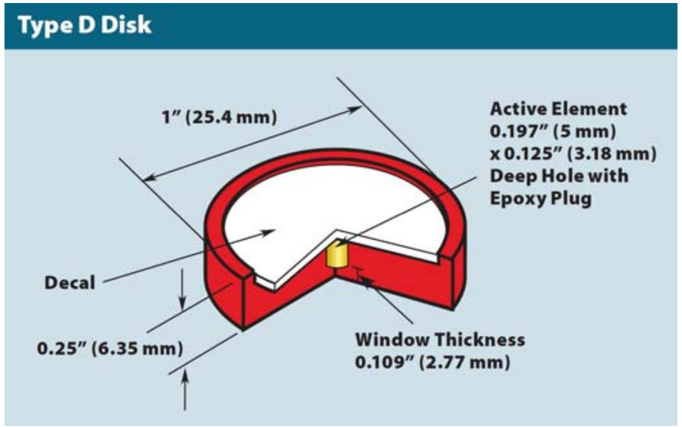
EUROPEAN COMMISSION JRC

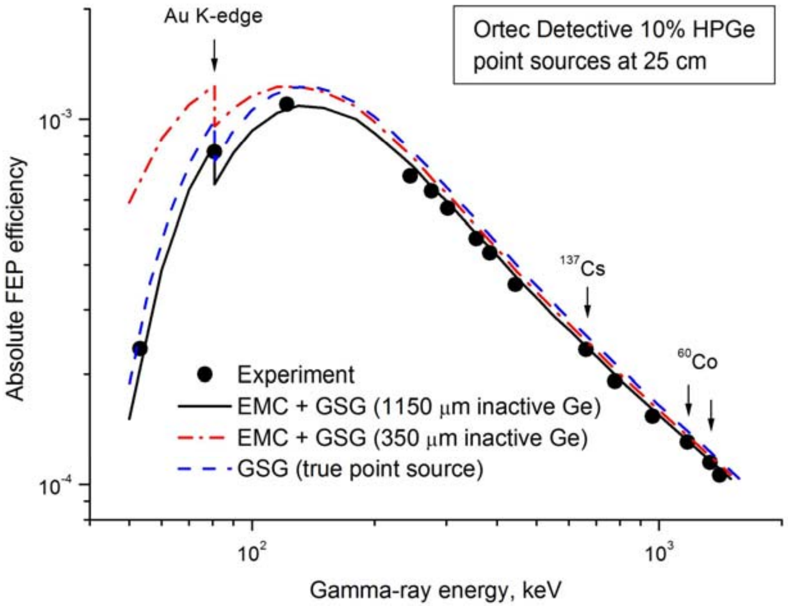
Institute for Transuranium Elements

Technical Report: JRC-ITU-TN-2009/25

GSG Version 2: Experimental Validation

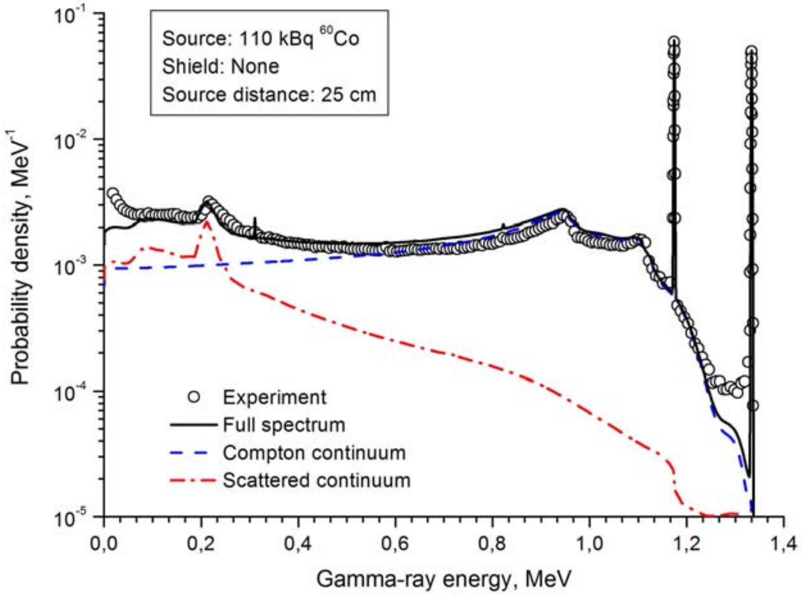
Type D Disk source: Eckert & Ziegler Isotope Products, Reference & Calibration Sources, Product Information

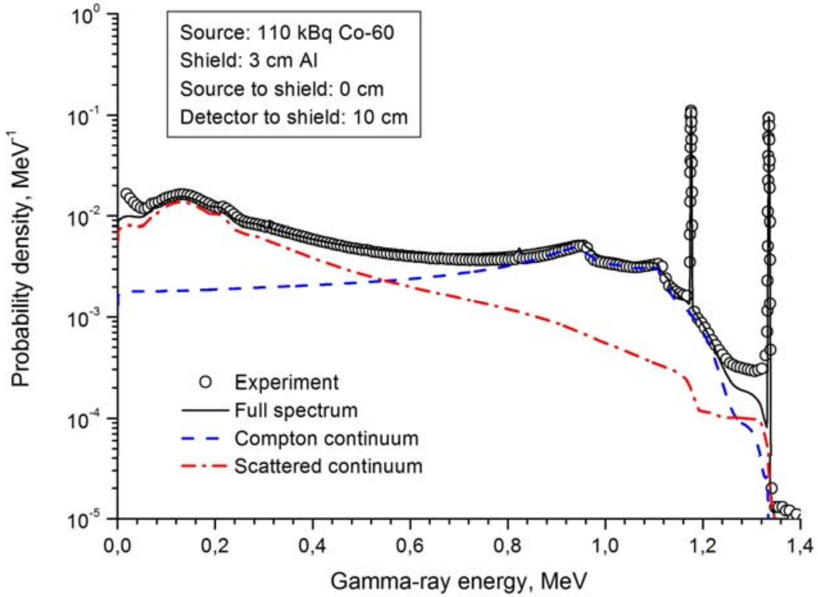


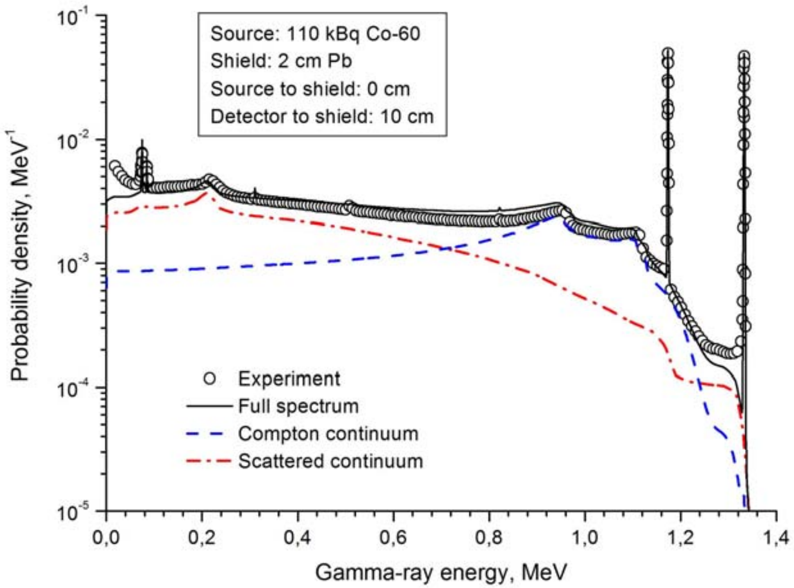


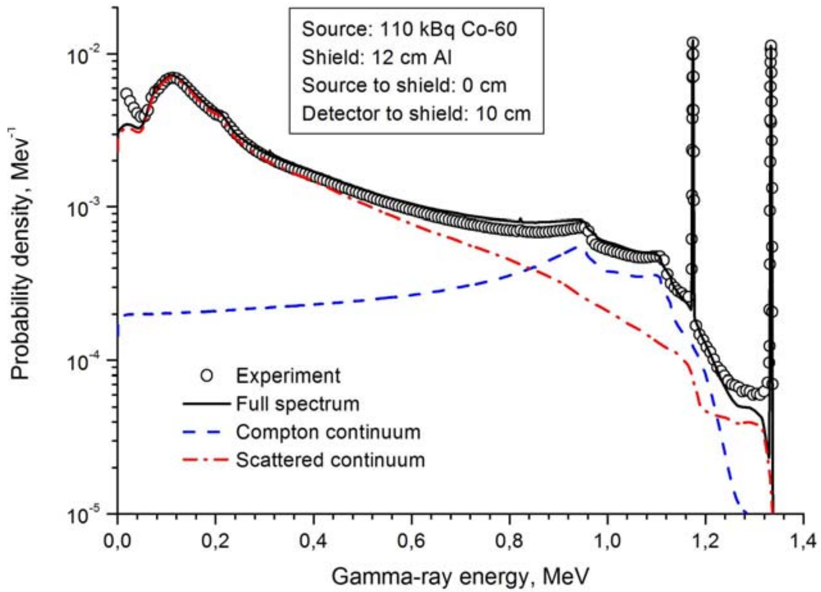
Experimental room: L × W × H = 3.3 × 3.8 × 3.5 m³.
Shields (20 × 20 cm²): Pb (2 cm) and Al (3 cm, 12 cm).
Detector: 10% Ortec Detective, HPGe ∅50 × 30 mm.
Shield to detector: 10 cm.
Source to shield: 0 cm.
Unshielded sources: at 25 cm distance.

GSG Version 2: Experimental Validation









GSG Version 2: Experimental Validation

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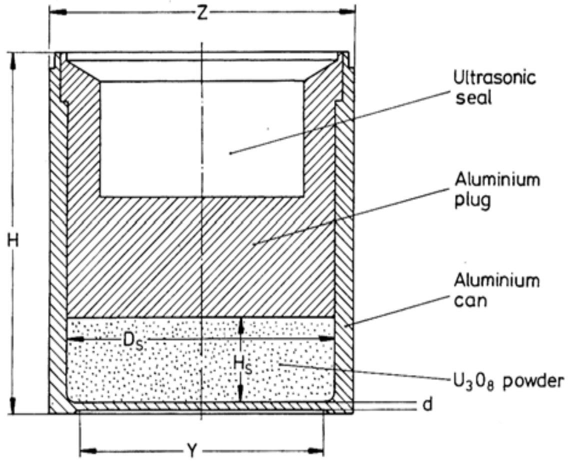
Detector: 10% Ortec Detective, HPGe ∅50 × 30 mm.
Shield to detector: 10 cm.
Source to shield: 0 cm.
Unshielded source: at 10 cm distance.

CBNM-446 Uranium:

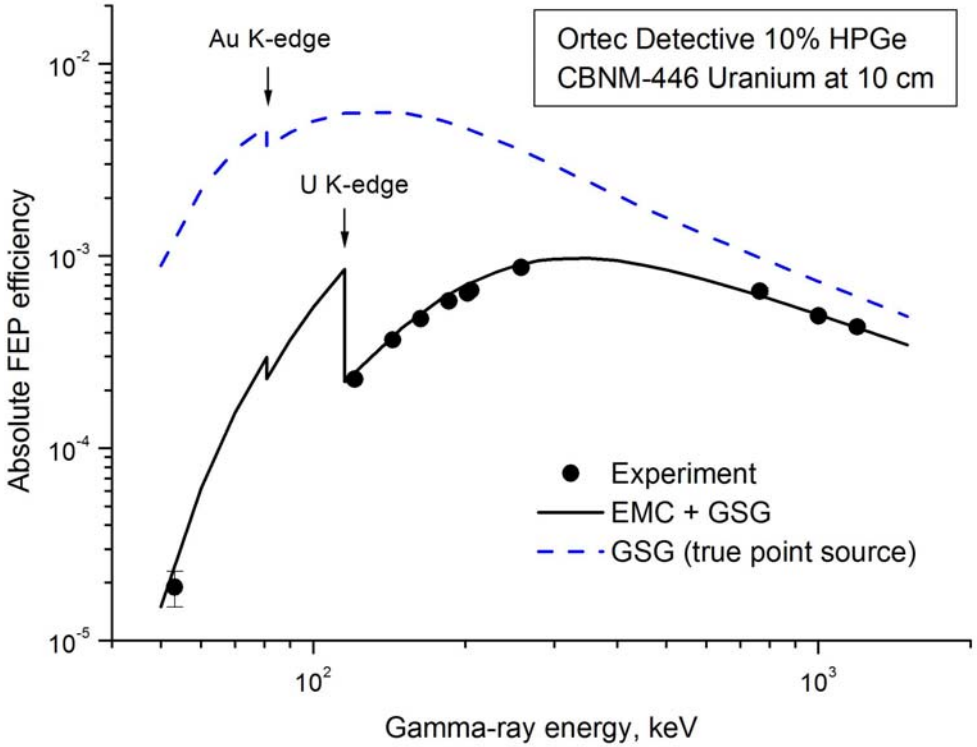
Separation date: 1979
U_3O_8, 200 g, 3.3 g/cm^3
Capsule: ∅ 8 × 9 cm
Sample: ∅ 7 × 1.58 cm
Al window: 0.2 cm

^{232}U – 4.1 ppt
^{234}U – 0.0359 wt %
^{235}U – 4.4623 wt %
^{236}U – 0.0068 wt %
^{238}U – 95.495 wt %



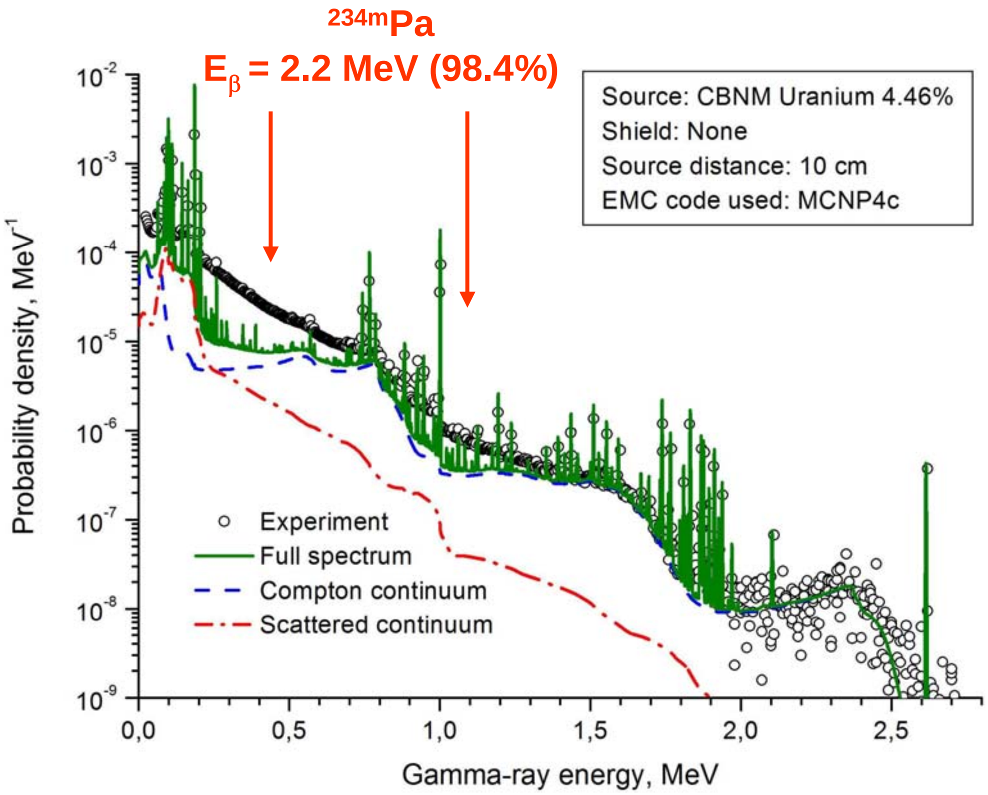
Nuclide	Activity	Nuclide	Activity
^{234}U	14.1 MBq	^{219}Rn	128 Bq
^{238}U	2.02 MBq	^{211}Pb	128 Bq
^{234m}Pa	2.02 MBq	^{211}Bi	128 Bq
^{234}Pa	3.03 kBq	^{212}Pb	438 Bq
^{234}Th	2.02 MBq	^{212}Bi	438 Bq
^{235}U	607 kBq	^{224}Ra	438 Bq
^{231}Th	607 kBq	^{208}Tl	157 Bq
^{231}Pa	372 kBq	**Total**	**21.4 MBq**

Unshielded CBNM-446: FEP efficiency

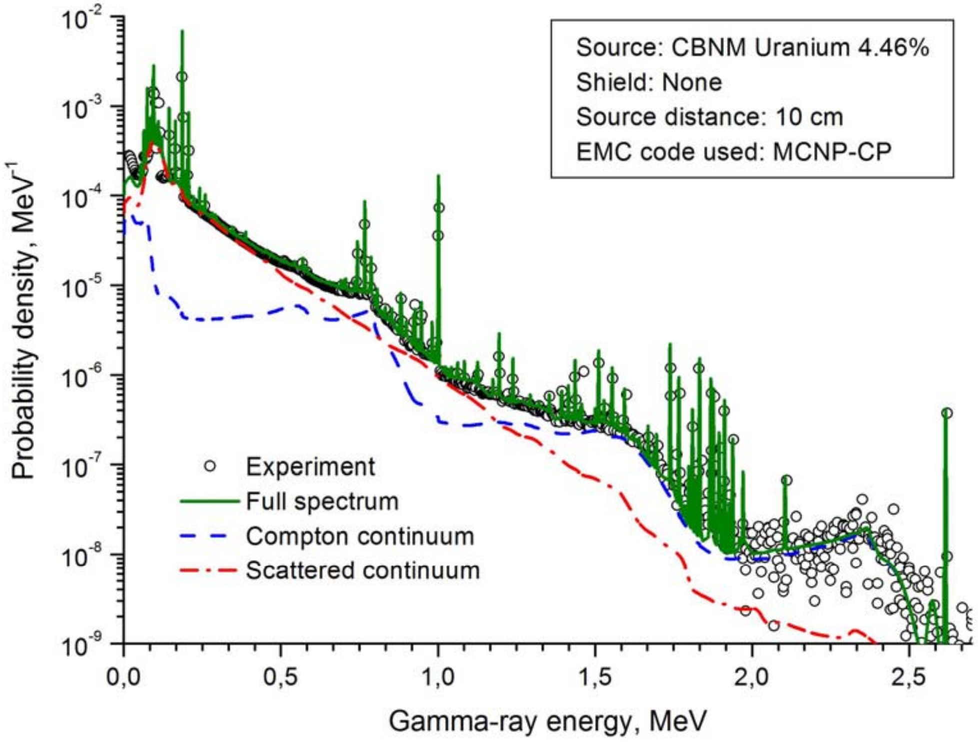


Unshielded CBNM-446

EMC option: MCNP4c



EMC option: MCNP-CP

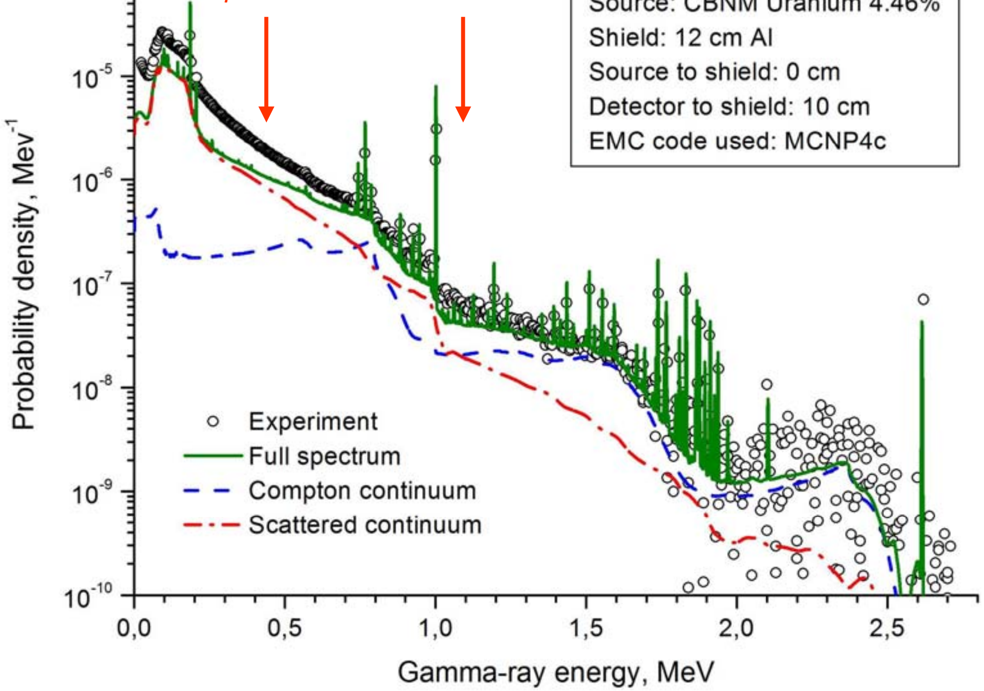


CBNM-446 shielded with 12 cm Al

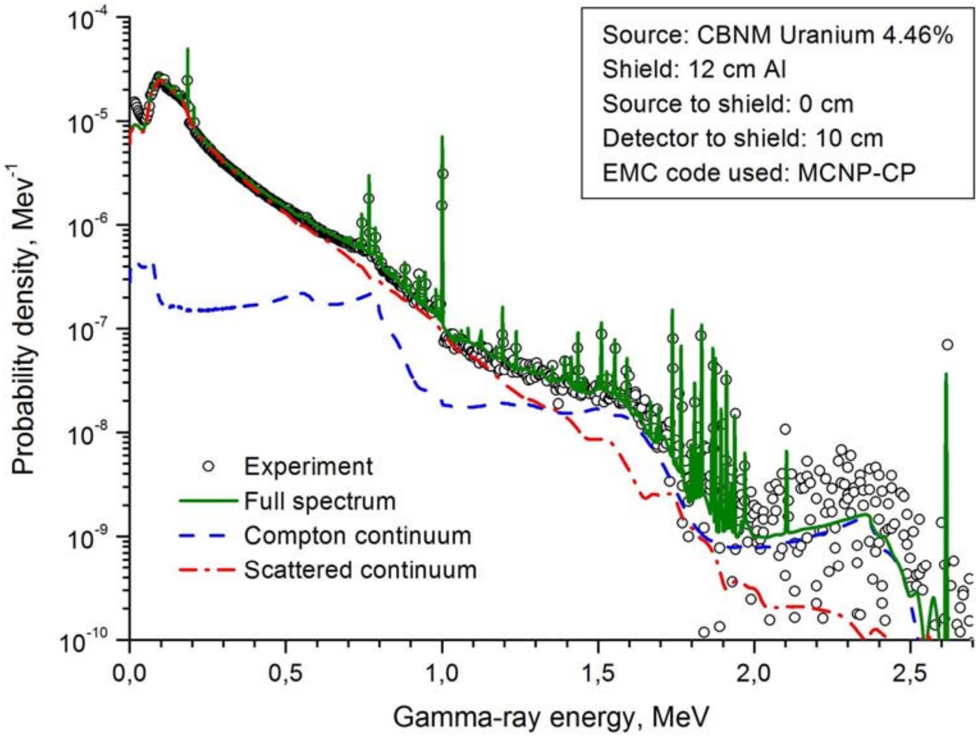
EMC option: MCNP4c

^{234m}Pa

E_β = 2.2 MeV (98.4%)

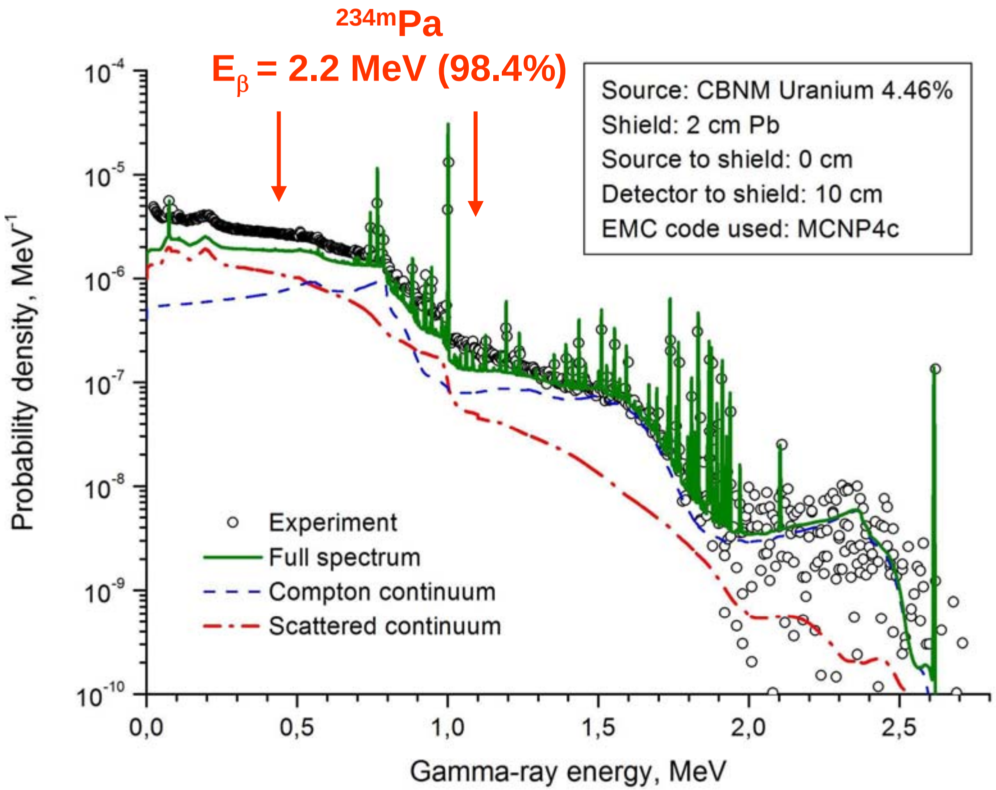


EMC option: MCNP-CP

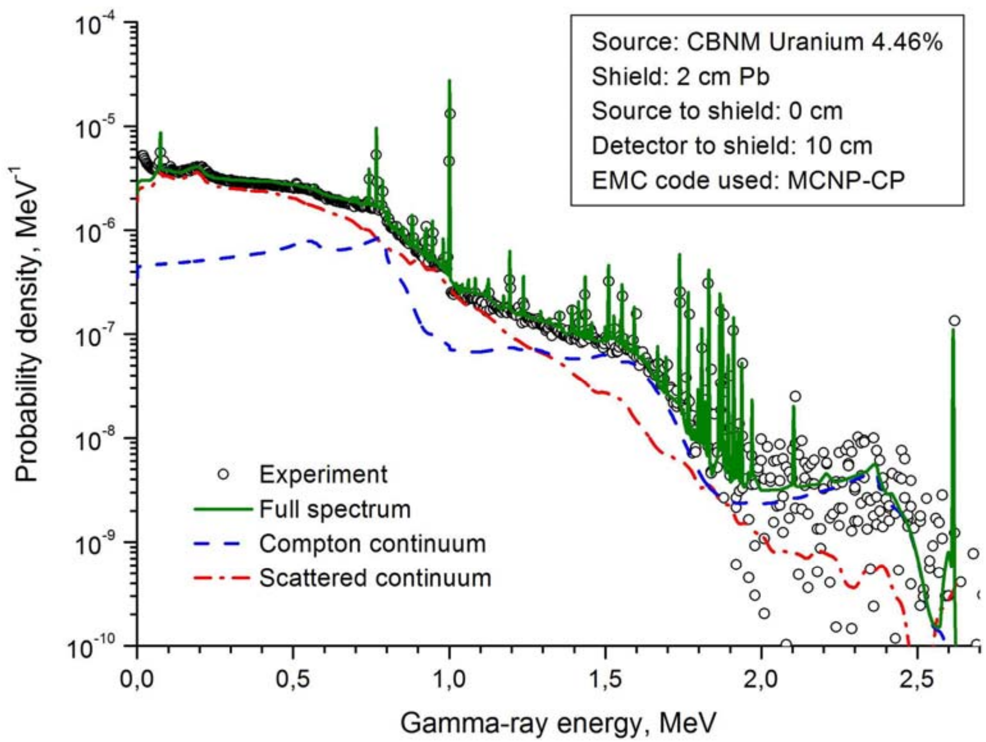


CBNM-446 shielded with 2 cm Pb

EMC option: MCNP4c



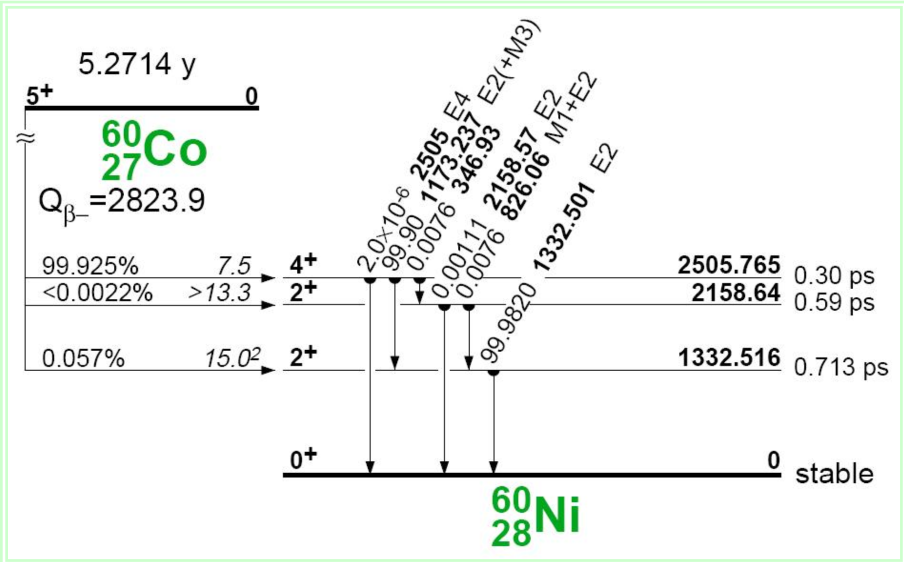
EMC option: MCNP-CP

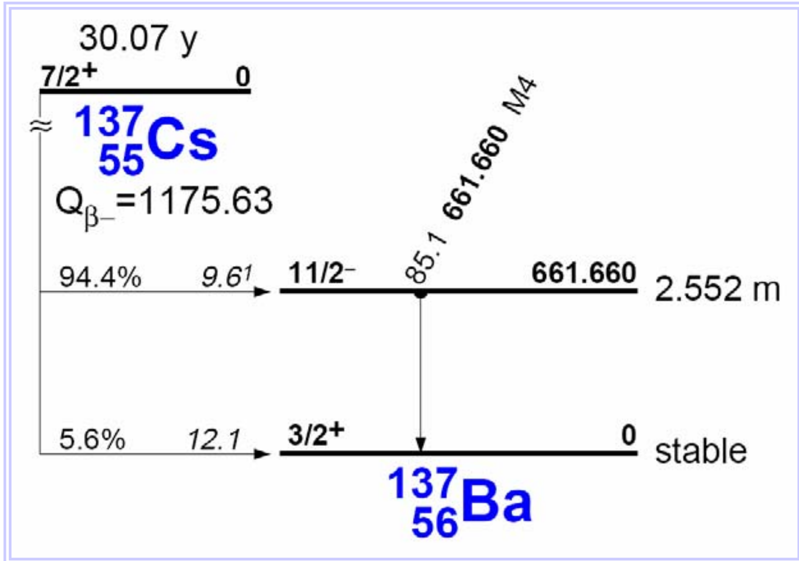


Thanks !

nucleonica

1. **The measurement setup is similar to the default configuration "NaI, L × D = 1 in × 2 in (default)". You are going to calibrate it using the 1 MBq ^{60}Co and 1 MBq ^{137}Cs reference gamma sources. Approximately, how many statistical counts can you expect within 100 s in the corresponding gamma-spectra? Make the evaluations with and without backscattered photon contribution.**





**Answer: ^{60}Co - without backscatter photons ≈1.66·10^{5} and with backscatter photons ≈1.91·10^{5} counts,
^{137}Cs - without backscatter photons ≈1.06·10^{5} and with backscatter photons ≈1.18·10^{5} counts.**

2. You have to measure the 10 MBq ^{152}Eu source with NaI (3"×3") scintillation detector in the measurement setup similar to the default configuration "NaI, L × D = 3 in × 3 in (default)". In your disposal there are three lead filters – 1 mm, 3 mm and 5 mm thick. Find the right combinations of the filters, which would make the measurement possible, assuming that your electronics can cope only with input count rates below 20 kcps (kilo counts per second). Check if the same electronics and filters will allow you to perform the measurement in the configuration "HPGe, coaxial, p-type, rel. eff. 150% (default)".

Answer: Valid filter combinations: 3 mm + 5 mm (18.8 kcps) and 1 mm + 3 mm + 5 mm (17.2 kcps). The electronics is not suitable for the configuration with 150% HPGe detector since even for the thickest filter combination the predicted input count rate is 22.6 kcps.

3. What is the relative efficiency of the HPGe detector with crystal length – 30 mm, crystal diameter – 50 mm, rear contact length – 20 mm, rear contact diameter – 10 mm, inactive Ge – 1.5 mm, cap thickness – 1 mm Al, and crystal to cap distance – 5 mm? What crystal length doubles the detector relative efficiency?

Answer: Relative efficiency = 10.5%. Crystal length L = 46.5 mm gives 21% relative efficiency.

4. **The 1 g natural uranium sample (^{234}U – 0.000055 g, ^{235}U – 0.0072 g, ^{234}U – 0.992745 g) was measured twice on the same NaI (3"×3") scintillation spectrometer (configuration "NaI, L × D = 3 in × 3 in (default)"). The first and the second measurements were performed for 100000 s respectively 10 days and 1 year after the uranium separation. What are the relative contributions of ^{235}U and ^{238}U to the gamma-spectrum measured in both cases? When modeling the spectra, use 1 mm Pb filter to imitate the self-attenuation properties of the sample.**

Answer: After 10 days ^{235}U - 76% and ^{238}U - 24%; after 1 year ^{235}U - 46% and ^{238}U - 54%.

5. **Based on the gamma-spectrometric examination of a source, the presence of ^{60}Co with activity 100 kBq was revealed. Which of the default GSG measurement configurations are suitable for detecting an additional presence of 50 Bq of ^{241}Am in the same source by performing a 1000 s long measurement?**

Answer: Configurations with LEGe and BEGe detectors. The respective MDAs are 12,2 Bq and 18,6 Bq.